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16. Abstract

This document describes the initial experimental program and mission requirements for a bilateral U.S./Canadian satellite synthetic aperture radar (SAR) system named FIREX (Free-Flying Imaging Radar Experiment) for renewable resources. The recommended spacecraft SAR is a C-band and L-band VV polarized system operating at two angles of incidence ($\sim 15^{o}$ from nadir and 45-60^{o} from nadir) designated as a research instrument for crop identification, crop canopy condition assessments, soil moisture condition estimation, forestry type and condition assessments, snow water equivalent and snow wetness assessments, wetland and coastal land type identification and mapping, flood extent mapping, and assessment of drainage characteristics of watersheds for water resources applications. This SAR system is complementary to other spaceborne imagers which use the visible and infrared portions of the electromagnetic spectrum. A near term research program is described to address specific mission design issues such as the preferred incidence angles for vegetation canopy measurements and the utility of a dual frequency (L- and C-band) or dual polarization (like and cross) system as compared to the baseline system.

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ABSTRACT

This document describes the initial experimental program and mission requirements for a bilateral U.S./Canadian satellite synthetic aperture radar (SAR) system named FIREX (Free-Flying Imaging Radar Experiment) for renewable resources. The recommended spacecraft SAR is a C-band and L-band VV polarized system operating at two angles of incidence ($\sim$15° from nadir and 45-60° from nadir) designated as a research instrument for crop identification, crop canopy condition assessments, soil moisture condition estimation, forestry type and condition assessments, snow water equivalent and snow wetness assessments, wetland and coastal land type identification and mapping, flood extent mapping, and assessment of drainage characteristics of watersheds for water resources applications. This SAR system is complementary to other spaceborne imagers which use the visible and infrared portions of the electromagnetic spectrum. A near term research program is described to address specific mission design issues such as the preferred incidence angles for vegetation canopy measurements and the utility of a dual frequency (L- and C-band) or dual polarization (like and cross) system as compared to the baseline system.

FOREWORD

This document is one of a series describing the Free-Flying Imaging Radar Experiment (FIREX) mission requirements:

Science Requirements for Free-Flying Imaging Radar (FIREX) Experiment for Sea Ice, Renewable Resources, Nonrenewable Resources, and Oceanography, JPL Publication 82-32.

Sea Ice Mission Requirements for the U.S. FIREX and Canada RADARSAT Programs, JPL Publication 82-24.

FIREX Mission Requirements Document for Nonrenewable Resources, JPL Publication 82-46.

FIREX Mission Requirements Document for Renewable Resources, JPL Publication 82-47.

PREFACE

The FIREX (Free-Flying Imaging Radar Experiment) Renewable Resources Mission Requirements Document (MRD) was prepared by the members of the FIREX Renewable Resources Study Team listed below.

<u>FIREX Renewable Resources Study Team</u>

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The team held its first meeting on May 20-21, 1981, at the NASA Goddard Space Flight Center. An outline of the MRD was prepared, and writing assignments were made. Drs. Carver, Paris, and Ulaby met on June 26, 1981, at the NASA Johnson Space Center to assemble the team inputs and to finish the first draft of the MRD. Drafts were distributed to the team members for review and comment. Dr. Paris performed the final editing of the present manuscript.

The team acknowledges the helpful comments of Dr. Kumar Krishen (NASA/JSC), Mr. Norman Hatcher (NASA/JSC), and Dr. Thomas Schmugge (NASA/GSFC).

Also, the team is indebted to the hundreds of scientists, technicians, and students who led and participated in previous research efforts concerning the use of radar for renewable resources.

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Jack F. Paris
September, 1981

GLOSSARY, SYMBOLS, AND ACRONYMS

Item	Definition
AgRISTARS	Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (a joint NASA, USDA, and NOAA program in FY80-87)
ASME	Agricultural Soil Moisture Experiment (conducted in 1978 at a site near Colby, Kansas, with KU, TAMU, U. Ark., and NASA/JSC)
C130B	NASA C-130B aircraft (has radar scatterometers at P-, L-, C-, and Ku-band)
C-band	3.9-6.2 GHz or 4.8-7.7 cm. (Specifically, 5.3 GHz or 5.7 cm)
CCRS	Canadian Centre for Remote Sensing, Ottawa, Ontario, Canada
CCT	Computer compatible tape
Classification Accuracy	Percent of fields or resolution elements correctly identified
cm	Centimeters
Co.	County
commission error	Incorrect inclusion of a pixel in a given class
C-SAR	C-band SAR (either the Canadian C-band SAR or the NASA C-band SAR)
Cross pol	Cross polarization (either HV or VH)
CV580	Canadian Convair 580 (has L-, C-, and/or X-band SAR's and a K-band radar scatterometer)
CV990	NASA CV990 aircraft (will have C- and X-band SAR in FY83)
dB	deciBel, $X_{dB} = 10 \log X$, where X is a ratio

Item	Definition
DEMR	Canadian Department of Energy, Mines, and Resources
dual frequency	For this study, an L- and C-band SAR system (e.g., L_{VV} and C_{VV})
dual polarization	For this study, a like and cross polarized system (e.g., C_{VV} and C_{VH})
E	East
ERIM	Environmental Research Institute of Michigan, Ann Arbor, Michigan
error matrix	A matrix showing the distribution of classified field labels versus ground truth labels (includes omission and commission errors and correct classifications)
ET	Evapotranspiration (evaporation -- water loss from the soil to the air; transpiration -- water loss from the soil to the plant and eventually from the plant to the air)
field capacity	The condition of a wet soil after water is depleted by gravity induced drainage -- water can be added to a soil at field capacity until saturation (all void space filled with water) is reached
FIREX	Free-Flying Imaging Radar Experiment (U.S. name for Canadian RADARSAT)
FSS	Field Spectrometer System (visible-infrared spectrometer borne by NASA helicopter)
FY	U.S. fiscal year (October 1 through September 30)
g	Grams
GHz	GigaHertz, 1×10^9 cycles per second
ground truth	Estimates of ground (surface) conditions made by ground instruments or personnel (not without error)

Item	Definition
growing season	Time of the year from planting to harvest. The season for crops in this report in the Northern Hemisphere runs from April through October.
GSFC	NASA Goddard Space Flight Center, Greenbelt, Maryland
GSS	NASA/JSC Ground-based Scatterometer System (operates at L-, C-, and Ku-band)
GVI	Green Vegetation Index (a measure derived from Landsat/MSS data that indicates how similar an object is to a full, green, healthy canopy so far as Landsat/MSS data is concerned
GVIR	A Green Vegetative Index derived from radar data
HH	A radar that transmits using horizontal polarization and receiver using horizontal polarization (a like polarization system)
HV	A radar that transmits using horizontal but receives using vertical polarization (a cross polarization system)
Hdqs.	Headquarters
Hz	Hertz (cycles per second)
ID	Identification -- a process in which crop types, for example, are separated according to differing spectral characteristics
infrared	Electromagnetic region from visible to microwave (0.7 μm to 1000 μm or 0.1 cm)
incidence angle	Angle between local nadir and slant path of a radar ray (not same as spacecraft transmit/receiver angle)
JSC	NASA Lyndon B. Johnson Space Center, Houston, Texas

Item	Definition
JPL	Jet Propulsion Laboratory, Pasadena, California.
°K	Degree Kelvin (absolute temperature or brightness temperature)
$K	Thousands of dollars
K-band	12-36 GHz or 0.83 - 2.5 cm
km	Kilometer
KU	University of Kansas, Center for Research, Inc., Lawrence, Kansas
Ku-Band	~13.3 GHz or 4.4 cm
LAI	Leaf Area Index -- total leaf area (one side) divided by horizontal area of plot containing the plants
Landsat	Satellite platform first launched into polar sun synchronous Earth orbit in July 1972 (MSS and TM (future) are carried by the Landsat)
L-band	0.4-1.5 GHz or 7.7-75 cm (in this report, "L-band" may also refer to the portion of S-band from 1.5-3.9 GHz) (Specifically, 1.275 GHz or 23.5 cm)
like pol	Like polarization (either HH or VV)
log	Logarithm to the base 10
L-SAR	L-band SAR (either SIR-A, SIR, JSC C-band SAR, or Canadian C-band SAR)
m	Meters
MARS	Mobile Agricultural Radar Scatterometer (KU scatterometer that operates at K-band or C-band)
MAS 1-8	Microwave Active Spectrometer (KU radar scatterometer that operates from 1-8 GHz)
MAS 8-18	MAS that operates from 8-18 GHZ

Item	Definition
microwave	Electromagnetic from 0.1 to 133 cm (0.225-300 GHz)
MRD	FIREX Mission Requirements Document
MSS	Multispectral (sic) Scanner System (a multiband scanner on Landsat that operates a 0.5-0.6 μm (MSS4), 0.6-0.7 μm (MSS5), 0.7-0.8 μm (MSS6), and 0.8-1.1 μm (MSS7)
multiband	System using several bands that are close spectrally
multispectral	System using several bands that are far from each other spectrally (e.g., visible and radar)
multidate	Taken on several days (at same time)
multitemporal	Taken at several times on same day
N	North
NASA	U.S. National Aeronautics and Space Administration, Washington, D.C.
N.D.	North Dakota
n.mi.	Nautical mile
NS001	Same as TMS
NSTL	NASA National Space Technology Laboratory, NSTL Station, Mississippi
omission error	Incorrect exclusion of a pixel from a given class
P-band	0.225-0.4 GHz or 75-133 cm
plant moisture content	Mass of plant water (g) in the above ground portion of a plant in the plants growing in a unit area (m^2) of ground
RADAR	Radio Detection and Ranging (in this report, RADAR includes scatterometers that do not estimate range necessarily)

Item	Definition
RADARSAT	Canadian name for U.S. FIREX
RB57	NASA RB57 high altitude aircraft (carried NASA SAR's)
registration	The operation of lining up multiband, multidate, multitemporal, or multispectral imaging or non-imaging data so that resolution elements correspond to the same ground (surface) area
revisit interval	The time period between successive ground coverage for a given point for the same or similar sensor
S	South
SAR	Synthetic aperture radar imager
S-band	1.5-5.0 GHz or 6-20 cm
SBI	Soil Brightness Index (a measure of soil reflectance in the MSS bands)
SCAT	Radar scatterometer -- a nonimaging precision instrument for measuring σ° from ground, aircraft, or spacecraft platforms
sec	seconds
SIR	Shuttle Imaging Radar
SM	AgRISTARS Soil Moisture Project
spatial resolution	The size of the surface area viewed during a sensor measurement (in this definition, the contrast of the object to its background is not taken into account)
SPOT	A French pushbroom, visible- and near-infrared imager planned for the mid-1980's
SR	AgRISTARS Supporting Research Project
surface soil moisture	Either the average moisture content of the surface soil (down to 2-5 cm) or the water equivalent thereof

Item	Definition
swath width	The horizontal size of the total width of the ground area viewed during a sweep of a remote sensor
TAMU	Texas A&M University
T_B	Brightness temperature (a reference temperature that allows one to predict the spectral radiance of the emitted radiation in simple term -- not equal to the actual temperature of the radiating object)
TM	NASA Thematic Mapper (a seven band scanner that operates from 0.4 μm to 2.7 μm (6-band) and at the 10 μm band)
TMS	Thematic Mapper Simulator (an aircraft scanner that operates in the same bands at the TM)
U. Ark.	University of Arkansas
U.S.	United States of America
USDA	U.S. Department of Agriculture
VV	A radar that transmits using vertical polarization and receives using vertical polarization (a like polarized system)
VH	A radar that transmits using vertical polarization and receives using horizontal polarization (a cross polarized system)
visible	A portion of the electromagnetic spectrum for 0.4-0.7 μm
W	West
W_V	Plant moisture content
$\bar{W}_V$	10 log W_V
X-band	6.2-12 GHz or 2.5-4.8 cm

Item	Definition
X-SAR	An X-band SAR (many examples in the U.S. and Canada)
YMD	AgRISTARS Yield Model Development Project
ρ	Correlation coefficient
σ^{o}	Backscattering coefficient or differential cross section (represents total backscattering cross section per unit horizontal area)

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I. EXECUTIVE SUMMARY

SECTION SUMMARY

- This report is the U.S. Renewable Resources Study Team's preliminary Mission Requirements Document for agriculture, soil moisture, forestry, snow, wetlands, coastal lands, flooding, and drainage applications.

- The team recommends the following minimum SAR system parameters for the research spacecraft system:
  - C-band VV and L-band VV
  - two incidence angle ranges; ~10-20° and 45-60° from the nadir
  - revisit interval: 10 days
  - swath width: 130 km
  - spatial resolution: 30 m (4 looks)
- The team recommends an experimental program in FY82 to address issues of:
  - best choice of incidence angle for crop monitoring (in the range of 45-60°?)
  - value of the addition of dual frequency or dual polarization
  - best practical combination of revisit interval, spatial resolution, and swath width

I. EXECUTIVE SUMMARY

This Mission Requirements Document, prepared by the U.S. Renewable Resources Study Team, summarizes (1) the major potential renewable resources applications of L-band (1.275 GHz) and/or C-band (5.3 GHz) synthetic aperture radar (SAR) imagery acquired from an orbital free-flyer satellite, (2) key radar parameter, specific research issues (e.g., recommended angles, frequencies, or polarizations) which must be addressed in order to specify the SAR satellite mission requirements, (3) an experimental program for FY82 which will address those key research issues, and (4) a specification of the mission requirements for a SAR to be used in a future satellite based research program. Although this document focuses on SAR mission requirements, the philosophy adopted is that SAR imagery is complementary to visible and infrared imagery in the context of potential applications and that both types of imagery must be considered in an eventual mission definition.

A. POTENTIAL RENEWABLE RESOURCES APPLICATIONS

The Renewable Resources Study Team has identified four major potential applications of spaceborne L-band and/or C-band SAR imagery, which are identified in priority order in Table I-1. Each of these potential applications is discussed in detail in Section III of this report along with the scientific justification for the potential of SAR imagery. It should be noted that priority category 4 is a combination of three diverse hydrological applications and that a further subdivision of priorities among these three was not possible.

TABLE I-1.- RENEWABLE RESOURCES POTENTIAL APPLICATIONS FOR SPACECRAFT L- AND/OR C-BAND APPLICATIONS

Priority Category	Potential Applications
	Primary Applications
1	Agricultural crop identification, area estimation, and canopy condition assessment.
2	Soil moisture condition assessment for agricultural and hydrological applications.
	Secondary Applications
3	Forest species identification, area estimation, and canopy condition assessment.
4	Wetlands and coastal land cover identification and area estimation, snow wetness and water equivalent, flood extent mapping.

The top two potential applications are viewed as of primary importance, and the bottom two are still high priority but of secondary ranking. The highest priority potential application is the identification, area estimation, and condition assessment for major agricultural crops such as corn, wheat, soybeans, barley, sorghum, rice, cotton, and sunflowers using SAR imagery either alone or in combination with visible/infrared imagery [e.g, Landsat Multispectral Scanner (MSS) or Thematic Mapper (TM)]. The second-ranked potential application is in mapping and monitoring of soil moisture over a wide range of field roughnesses and vegetative covers, for use in both crop growth and yield models and hydrological models.

B. KEY RADAR PARAMETER RESEARCH ISSUES

A mission requirements specification for a SAR satellite must include the desirable frequency(ies), angle(s) of incidence, polarization(s), resolution(s), and revisit interval(s). Radar parameters of less crucial importance include swath width, dynamic range, registration, etc. The optimum radar parameters must be specified in the context of both SAR and visible/infrared co-registered images; considerations of SAR alone will not allow a meaningful specification of optimum remote sensor system parameters.

A great deal of radar signature research has been conducted in the past decade and has revealed that C-band or higher frequency radar backscattered signals obtained at high incidence angles are sensitive principally to the water content in a vegetative canopy. Indeed, these higher-frequency radars may be used to distinguish among crop types when measurements are made at periodic intervals through the growing season. These experimental studies have also revealed that a C-band radar operating in the 10-20° incidence angle range shows a strong sensitivity to soil moisture in the top few centimeters of fields with a wide range of surface roughness and vegetative covers. Significant effects of row structure and row direction have been observed at all frequencies, especially near L-band and near 20° incidence. Most of these experimental studies have been conducted using truck-based boom-mounted radar spectrometers or airborne scatterometers in the 1-18 GHz frequency range.

The specific radar parameter research issues of interest in the present study are more narrowly focused on the question of the utility of L- and/or C-band SAR imagery for the potential applications listed in Table I-1. Key research questions are:

- When considering data from both radar and visible and infrared sensors, what are the best choices for wavelength, incidence angle, and polarization?
- What should the revisit time be?
- What is the best combination of resolution and number of looks?
- What improvement would be realized by using both L- and C-band?
- What improvement would be realized by using two polarizations, e.g., like and cross?

These are partially answered in Table I-2, with some items flagged by the symbol r as key radar parameter issues.

1. INCIDENCE ANGLES FOR VEGETATION (ESP. CROP) APPLICATIONS

Initial results suggest that the preferred incidence angles for vegetation canopy identification and condition assessment by SAR are in the 45-60° range due to the fact that this configuration minimizes surface scatter from the soil

TABLE I-2.- RESEARCH OBJECTIVE AND SAR MISSION REQUIREMENTS

Potential Applications	Revisit Time	Incidence Angle 15°	25°	35°	45°	55°	65°	Frequency/Polarization L_{VV}	L_{HH}	L_{HV}	C_{VV}	C_{HH}	C_{HV}	Improvement L+C	both polar
	P = Prime	A = Acceptable				r = Research issue									
1. Crop separability, ID, condition	10 days	-	-	-	A^r	P	-	P	A	-	P	A	-	MED^r	MED^r
2. Soil moisture	10 days^r	P_{HH}	A_{HV}	-	-	-	-	-	-	A^r	A	P	A^r	LO/MED^r	HI^r
3. Forestry: Areal cover, species ID and stress	10-90 days	A	-	-	A^r	P	-	P	A	-	P	A	$?^r$	HI^r	HI^r
4. Other objectives:															
• Snow cover	10 days	-	-	-	A	P	-	-	-	-	P	A^r	A	LO	MED^r
• Wetlands & coastal map	10 days	A	A	A	A^r_r	P	-	A	A	$?^r$	A_r	A^r	$?^r$	MED	HI
• Flood extent	10 days	-	-	-	A	P	-	A	A	A	A	A	A	LO	LO
• Drainage map	10 days	-	-	A	P	A	-	-	A	-	-	P	-	MED	HI

The spatial resolution required for all satellite-based research is specified to be 30 m × 30 m using 4 independent samples per resolution element.

The revisit times are specified to be 10 days for the research system. In an operational system that might follow, the revisit interval would probably have to be less (1-5 days) for soil moisture and snow applications.

under the canopy and maximizes volume scattering from water contained in the canopy. However, additional research is needed to establish firmly these results for L- and C-band SAR's. Multidate data over several crops, forest types, and wetlands types at L-band and C-band for angles from 45-60° are needed to allow researchers to address this issue.

2. DUAL FREQUENCY UTILITY

The team recommends both C-band and L-band based on the approximately 4 to 1 wavelength ratio and the importance of wavelength to volume and surface back-scattering. The performance of a dual frequency L- and C-band system needs to be quantified as compared to a C-band system alone for crops, forest types, and soil moisture. This issue should be addressed during FY82. Multidate like-polarization data are needed for L-band and C-band to address this issue.

3. DUAL POLARIZATION UTILITY

The added performance of a dual polarization (like and cross) system needs to be determined as compared to a like-polarized system alone for crops and snow cover. Multidate dual polarization C-band and L-band data are needed for this issue.

4. SPATIAL RESOLUTION, REVISIT INTERVAL, AND SWATH WIDTH FOR SOIL MOISTURE

According to one computer simulation study, sensing soil moisture can be done at relatively low resolution (~100 m) for the 15° C-band HH configuration. The simulation work is being continued with more realistic model assumptions concerning the spatial distributions of plant and soil characteristics. Also, the interleaved constraints of viewing angle range, spatial resolution, swath width, and revisits interval need to be considered to determine if a practical and useful SAR mission configuration can be designed for soil moisture surveying. To support the research for this issue, the team recommends a nominal 30 m (4 looks) spatial resolution since one may degrade that resolution if desired.

C. EXPERIMENTAL PROGRAM

An experimental program plan has been formulated to address the specific radar parameter research issues discussed above. As initially conceived, the plan envisioned the use of sets of L-, C-, and X-band calibrated SAR images of test sites mostly in the U.S., to be provided by the Canadian CV-580 SAR system. However, it was subsequently learned that acquisition and processing of CV-580 SAR data over U.S. test sites had to be handled contractually through the Environmental Research Institute of Michigan (ERIM) and that the associated costs of coverage of the recommended U.S. test sites would be prohibitively high. Therefore, as an alternative experimental strategy, a plan has been developed which utilizes the NASA C-130B L-band and C-band scatterometers, and the University of Kansas truck-borne radar spectrometer which can acquire data at both L-band and C-band. This plan also maximizes the use of other on-going FY81-82 investigations (e.g., AgRISTARS and Fundamental Research programs), in cooperation with the counterpart Canadian experimental program, and the detailed study of previously acquired but as yet unanalyzed L- and C-band scatterometer data taken over fields with various crop covers and soil moistures. This alternative plan is not as scientifically satisfactory as the original strategy which would use multidate calibrated L-band and C-band SAR image data sets, but is certainly adequate to answer the key research issues if carried out fully as detailed in this document.

A summary of elements of an experimental plan for the Renewable Resources Study for FY81-82 is shown in Table I-3. An examination of probable resources (equipment, time, and people) available for a realistic FY82 experimental research plan led the team to the following proposed experimental research plan, which is directed toward the top two potential applications of Table I-1.

1. OBJECTIVE AND SCOPE

The proposed FY82 research plan has the following objectives and scope.

a. To investigate the incidence angle response (45-60°) for a C-band and L-band VV-polarization SAR system to be used for crop identification, crop area estimation, and crop canopy condition assessments.

b. To quantify the added advantage of using a dual frequency and/or a dual polarization SAR system for crop identification, crop area estimation, and crop canopy condition assessments. L- and C-band will be considered; also, like and cross polarization will be considered.

c. To determine SAR parameters that would satisfy the soil moisture mapping requirements for revisit interval, incidence angle range, spatial resolution, swath width, and ground coverage. Specifically, the maximum radar revisit period (no. of days) that can be used reliably for agricultural and hydrological applications needs to be established as the main constraint for these interrelated parameters.

Funding constraints preclude an extension of the experimental program plan to cover the bottom two potential applications of Table I-1.

TABLE I-3.- RENEWABLE RESOURCES EXPERIMENTAL PROGRAM SUMMARY (Page 1 of 3)

Research Issues	Data sets needed	Recommended sites	Notes
		CROP IDENTIFICATION AND CONDITION ASSESSMENT	
• Incidence angle response • Improvement with L- and C-band? • Improvement with both like- and cross-polarization data	• Multidate, multiyear L- and C-band like- and cross-polarized radar data from 45°-60° for several crops with adequate ground truth data (truck spectrometers, airborne scatterometers, airborne SAR's)	• Melfort, Saskatchewan (Summer, 1982; joint program with Canada and United States; wheat, barley)	Canadian team furnishes CV-580 SAR data set; United States team furnishes University of Kansas truck spectrometer; estimated cost is $60K in FY82 under FIREX program.
		• Webster Co., Iowa (Summer, FY80-82; United States test site for corn and soybeans	AgRISTARS supersite. C-130B scatterometer data set and augmented ground truth needed. Estimated cost is $50K in FY82 under FIREX program.
		• Cass Co., N. Dak. (FY80-82; United States test site for wheat, barley)	AgRISTARS supersite. Complete analysis of microwave data taken under AgRISTARS program. No funding requested for FY82 from FIREX program.
		• Colby, Kansas (Summer, 1978; data set for irrigated corn, pasture, wheat stubble, fallow)	Complete analysis of high-angle C-band airborne scatterometer data. No funding requested.
		• Eudora, Kansas (FY75-77 summer data set for wheat, corn, soybeans, sorghum)	Analysis University of Kansas MAS 1-8 truck spectrometer data at C-band, L-band. Estimated cost is $25K in FY82 under FIREX program.

TABLE I-3.- Continued

Research Issues	Data sets needed	Recommended sites	Notes
SOIL MOISTURE MAPPING			
• Preferred revisit interval? • Spatial resolution and no. of looks? • Swath width?	• Multidate L- and C-band like and cross-polarized data from 10°-50° for several sites with adequate ground truth data	• Webster Co., Iowa (Summer, FY82; United States AgRISTARS test site - corn and soybeans)	AgRISTARS supersite. C-band soil moisture measurements with University of Kansas MAS 1-8 truck spectrometer over bare and vegetated fields. Estimated cost is $40K in FY82 under FIREX program.
• Improvement with two polarizations? • Improvement with two frequencies (L- and C-band)?	• Multidate C-band airborne SAR like-polarized data at 20° incidence for site with adequate ground truth	• Melfort, Saskatchewan (Summer, FY82; joint program with Canada and United States)	Acquire multidate CV-580 C-band SAR imagery at 20° angle (swath center) over fields with wide range of moistures. No funding included in United States experimental plan.
FOREST SPECIES IDENTIFICATION AND CONDITION ASSESSMENT			
• Incidence angle response? • Improvement with like and cross-polarization data? • Improvement with two frequencies (L- and C-band)?	• Multidate, multi-year L- and C-band like and cross-polarized aircraft SAR data from 45°-60° for deciduous and coniferous forests with adequate ground truth	• Petawawa site, Ontario	No funding included in United States experimental plan. Use Canadian data in joint program.
		• Kershaw Co., S.C.	No funding available for SAR data in FY82.
		• Clearwater Nat'l Forest, Idaho	No funding available for SAR data in FY82

TABLE I-3.- Concluded.

Research Issues	Data sets needed	Recommended sites	Notes
SNOW APPLICATIONS			
• Improvement with like- and cross-polarized data?	• Multidate C-band like- and cross-polarized 45°-60° scatterometer and SAR data for snow fields with adequate ground truth	• Minot, N. Dak.	No funding available in FY82 for new data
OTHER APPLICATIONS			
No new issues to be resolved; present data base must suffice			

2. SITES

The study sites recommended are located in Figure I-1 and are listed in Table I-3, with principal emphasis on the Melfort, Saskatchewan site (for small grains ID), Webster County, Iowa (both for corn and soybeans ID and for soil moisture revisit interval studies), and Eudora, Kansas (processing and analysis of FY75-77 archival data for wheat, corn, soybeans, and sorghum ID and condition). It may also be possible to utilize the CV-580 C-band SAR data over Melfort for joint soil moisture studies.

3. COSTS

A summary of the estimated NASA costs for FY82 experiments and studies is given in Table I-4. Section IV gives further details of the experimental program. A line item of $45K has been included to apply to aircraft operations approximate costs for the C-130B.

TABLE I-4.- SUMMARY OF ESTIMATED FY82 COSTS

Experiment	Purpose	Estimated Cost
1. Melfort, Saskatchewan	Acquisition of University of Kansas truck spectrometer data over small grains	$60K
2. Webster County, Iowa	C-130 C-band scatterometer data from corn and soybeans	$50K
3. Webster County, Iowa	University of Kansas truck spectrometer data for soil moisture studies	$40K
4. Eudora, Kansas	Processing, analysis of FY75-77 truck spectrometer data for wheat, corn, soybeans, sorghum	$25K
5. Aircraft acquisition costs		$45K
Total for FY82		$220K

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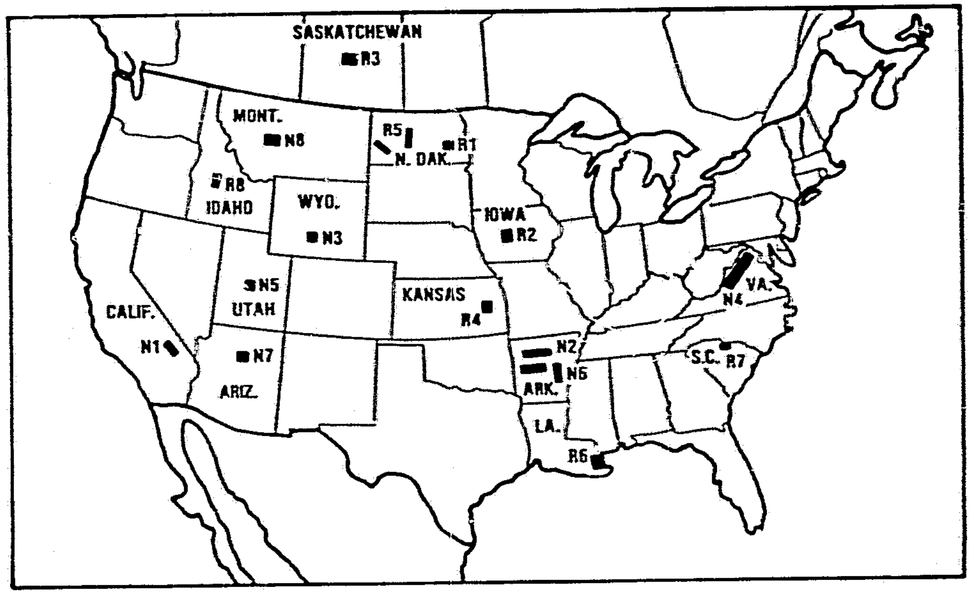
FIREX MISSION REQUIREMENTS STUDY

LAND RESOURCE TEST SITES



Site No.		Location	Renew	Non-Renew	Comments
prioritized	R1	Cass Co., N.D.	X		AgRISTARS Supersites — Crop
	R2	Webster Co., Iowa	X		separability and condition
	R3	Saskatchewan	X		U.S./Canadian ag. site
	R4	Eudora, Kansas	X		Soil moisture
	R5	Minot, N. Dakota	X		Snow
	R6	Mississippi/Louisiana	X	X	Wetlands/Coastal/Geobotany
	R7	Kershaw Co., S. Carolina	X		Forestry
	R8	Idaho	X		Forestry
prioritized	N1	Death Valley, California		X	Arid site
	N2	Arkansas		X	Geobotany, topographic test site
	N3	Patrick Draw, Wyoming		X	GEOSAT test site
	N4	Virginia		X	Geobotanical test site
	N5	San Rafael Swell, Utah		X	Semi-arid site
	N6	Little Rock, Arkansas		X	Gravel bars, wetlands test sites
	N7	Coconino Plateau, Arizona		X	Semi-arid site
	N8	Montana		X	USGS CUSMAP Project

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Figure I-1.- FIREX Test Sites.

D. SUMMARY OF MISSION REQUIREMENTS

The renewable resources SAR mission requirements summarized in Table I-5 are based on our present understanding of the available literature of radar backscatter research. Some of these findings may be modified as a result of the proposed experimental program discussed earlier. These SAR minimum requirements may be viewed as a least common denominator to the crop classification and soil moisture potential applications. They would allow a system with enough flexibility to permit the test and evaluation from space of the preliminary information extraction procedures based on truck radar spectrometer and airborne radar scatterometer measurements and analyses coupled with theoretical models.

TABLE I-5.- RECOMMENDED SAR MISSION REQUIREMENTS FOR RENEWABLE RESOURCES

SAR Parameter	Recommended Minimum Configuration
• Frequency	C-band and L-band
• Polarization	VV
<u>Low Angle Mode</u>	
• Angle of incidence	15°
• Resolution	30 m
• Number of azimuth looks	4
• Swath width	130 km
• Revisit interval	< 10 days
<u>High Angle Mode</u>	
• Angle of incidence	45°-60°
• Resolution	30 m
• Number of azimuth looks	4
• Swath width	130 km
• Revisit interval	< 10 days

Thus, the minimum system is a VV-polarized C-band and L-band SAR which operates simultaneously in both a low-angle and high-angle mode. The low-angle mode is principally for soil moisture mapping and the high-angle mode for crop type and forest species condition and identification. In addition, the synergism of a combination of visable/infrared data and SAR data (1-4 channels) may enhance system performance as compared to any one data source alone. Although the optimum revisit interval for soil moisture mapping may be as short as 1-2 days, in an operational mode, it is felt that the 10-day revisit interval required for crop classification would allow an adequate test of the soil moisture mapping concept in a research mode. Since no operational uses are envisioned for the research spacecraft SAR addressed here, it is not necessary that a 1-2 day revisit interval be specified. It would be most cost effective to investigate the question of needed revisit interval through simulations of spacecraft SAR data and truck-based experiments instead of through use of actual spacecraft SAR data acquired every day. The same is true for snow applications as well where the optimum revisit interval is probably less than the 10 day revisit interval recommended here for the research satellite.

II. INTRODUCTION

SECTION SUMMARY

- Canada and the United States are participating in a joint study to define the Mission Requirements for a free-flying SAR imager for ice mapping, ocean survey, non-renewable and renewable resources survey research.

- This report is the Mission Requirements Document (MRD) from the U.S. Renewable Resources Study Team.

II. INTRODUCTION

A. BACKGROUND

This MRD has been prepared by the U.S. Renewable Resources Study Team in response to a request by NASA as a component of the bilateral study of the U.S. (NASA) and Canada (Department of Energy, Mines and Resources -- DEMR) to define the parameters which are optimum for a spaceborne orbital free-flyer SAR. A similar document is being prepared by the parallel efforts of the Canadian Renewable Resources Study Team, and it is anticipated that the essential recommendations of both teams will be summarized and compared in a jointly authored MRD to be available by January of 1982.

The request for this document was generated as a result of discussions in 1980 between representatives of DEMR in Canada and NASA in the United States. It was concluded that both organizations have a mutual interest in undertaking bilateral studies to define a possible future joint NASA/DEMR SAR satellite program which would satisfy both the U.S. and Canadian requirements. These discussions resulted in the signing on November 26, 1980, of a bilateral plan to conduct jointly a 21 month (January, 1981, to October, 1982) Mission Requirements Study to define both immediate research and operational requirements that might support such a possible future program. Four major applications areas for study were identified: Ice, Oceans, Non-Renewable Resources and Renewable Resources. It was agreed that Canada would form a study team for each of these areas and that the U.S. would also form four parallel teams in each area. Furthermore, each team would develop either separate or bilateral MRD's. A bilateral study schedule was developed in which the preliminary MRD be available by the end of May, 1981, and in which the final MRD be available in January of 1982. It was anticipated that certain key SAR parameters could not be specified with the currently available data base and that a limited-duration truck-based and aircraft-supported experimental program might be necessary to define optimum frequencies, incidence angles, polarizations, revisit times, etc. necessary to specify the best set of mission requirements for a free-flyer orbital SAR.

Prior to this activity, a study (the SURSAT study) was performed by Canadian Astronautics, Ltd. in which the engineering feasibility was investigated for the designing of a SAR satellite which could provide routine operational monitoring of ice dynamics in the Canadian Arctic Sea. As a result of this study and subsequent analyses by the CCRS, a baseline SAR design was selected which specified multiple coverage by three separate, but identically-configured C-band SAR's (HH-polarized at an orbital altitude of 675 km). This same SURSAT report also studied the feasibility of an L-band SAR and listed similar parameters for it. The selection of a C-band baseline SAR design was made by the CCRS, with prime emphasis on operational monitoring of sea ice dynamics for use by the shipping industry.

The NASA Renewable Resources Study Team (hereafter called the team) was formed in May 1981 and held its first meeting at the NASA Goddard Space Flight Center. Teams for the other three areas were formed also. The team is chaired by Dr. Keith Carver (NASA Headquarters) and is co-chaired by Dr. Jack Paris (NASA Johnson Space Center). Other team members are Dr. Fawwaz Ulaby (University of Kansas), Mr. Michael Calabrese (NASA Headquarters), Dr. S. T. Wu (NASA National

Space Technology Laboratories), and Dr. Dorothy Hall (NASA Goddard Space Flight Center). At this initial meeting, the team was instructed to consider only L-band and/or C-band orbital SAR's, to provide a priority-ranked list of applications or research objectives, to identify any needed experimental programs which would specifically address unresolved issues, and to form a preliminary but considered opinion as to what the SAR parameters or range of parameters would likely be.

The team was charged with the tasks of identifying significant potential applications and research problems amenable to solution by synthetic aperture radar (SAR) image data (L-band, C-band or both) defining mission requirements for a prospective SAR, specifying needed complementary data sets, and formulating an FY82 experimental program necessary to help clarify which range of SAR parameters would be best for each research objective.

This document is the preliminary draft of the MRD for Renewable Resources. A final draft will result by January 1982, after joint future meetings with the counterpart Canadian team. The entire study will end by October 1, 1982, and a Final Report will be issued at that time.

In NASA parlance, this program is called the FIREX study and in the Canadian reports, the program is known as the RADARSAT study. If the bilateral Mission Requirements Study results in a decision to proceed with a jointly funded and managed SAR free-flyer, the name RADARSAT would be used. If this decision is not made, then the name FIREX would be used as a generic acronym for a NASA-sponsored free-flyer SAR and RADARSAT would describe a Canadian-sponsored separate free-flyer SAR.

B. PURPOSE AND ORGANIZATION OF THIS DOCUMENT

This MRD outlines the following:

- The major potential renewable resources applications of L-band and/or C-band SAR imagery acquired from an orbital free-flyer satellite.
- The key radar parameter research issues which need to be addressed in the context of the potential applications.
- An experimental program plan which will help resolve those key research issues.
- Specification of key SAR mission requirements which would be satisfactory to investigate the potential of imaging radar for the listed applications.

Wherever possible, an attempt has been made to include the key specific scientific findings (graphs, tables, etc.) which have pointed to the potential of imaging radar for use in the listed applications. All of these findings focus on L-band and C-band SAR's, and as such differ from past survey reports which had considered all frequencies from 1-18 GHz. This has revealed that much has been learned in the past decade about L-band and C-band radar signatures, but also points to weaknesses in our current understanding that must be rectified by a few very specific additional research investigations directed specifically at the FIREX mission requirements problem.

III. APPLICATIONS NEEDS AND MISSION REQUIREMENTS

SECTION SUMMARY

- This section addresses renewable resources research needs and related FIREX mission requirements

- Agricultural applications needs for improved crop production estimation:
  - more accurate crop identification (separation) for early season especially (compared to Landsat/MSS and TM based techniques)
  - more accurate crop area (proportions) estimations
  - additional or supplemental information on crop canopy conditions related to yield estimation

- Agricultural FIREX mission requirements and research issues (denoted by r):
  - revisit interval: $\leq$ 10 days
  - spatial resolution: 30 m × 30 m (4 samples)
  - incidence angle: 45-60° r
  - C-band VV and L-band VV (HH acceptable)
  - dual frequency utility? r
  - dual polarization utility? r

- Soil moisture applications needs:
  - Daily or bi-daily surface-zone soil moisture condition assessments
  - Useful for profile soil moisture model calibration, rainfall interpolation, flux estimation (surface evaporation and infiltration), and antecedent soil moisture condition estimation for agriculture and water resources applications

- Soil moisture FIREX mission requirements and research issues (denoted by r):
  - revisit interval: < 10 days
  - spatial resolution: 30 m × 30 m (4 samples) r
  - incidence angle: ~ 10-20°
  - C-band HH (C-band VV acceptable)
  - dual polarization utility? r
  - dual frequency utility? r
- Forestry applications needs:
  - more accurate forest type identification
  - more accurate assessment of forest canopy condition (moisture condition, timber volume)
- Forestry FIREX mission requirements and research issues (denoted by r):
  - revisit interval: 10-90 days
  - spatial resolution: 30 m × 30 m (4 samples)
  - incidence angle: 45-60° and 10-20°
  - C-band VV and L-band VV
  - dual polarization utility? r
  - dual frequency utility? r
- Snow, wetlands, coastal lands, flooding, and drainage applications needs:
  - periodic assessment of snow mass (areal distribution of water equivalent) and moisture (liquid) content for hydrological applications (water resources assessment)
  - mapping of wetlands and coastal lands for environmental assessments
  - assessment of extent of flooding (target of opportunity)
  - assessment of characteristics of watersheds concerning drainage and storm runoff (water resource and hazards)

- Snow, wetlands, coastal lands, flooding, and drainage FIREX mission requirements and research issues: requirements and issues are included in those stated above

III. APPLICATIONS NEEDS AND MISSION REQUIREMENTS

Potential renewable resources applications for the SAR system include agriculture, hydrology, forestry, and land cover information needs. A summary of the renewable resources applications and related SAR mission requirements was given in Table I-1. The items in Table I-1 are discussed in detail below. For each specific application, the team attempted to identify the revisit interval, spatial resolution, incidence angle, frequency, and polarization combination needed to conduct research based on satellite SAR data. Also, the team considered the improvement in performance that might be provided by the use of a combination of two frequencies and/or of two polarization combinations. Those mission requirements that are unclear and in need of further research are identified in Table I-1 by an r.

A. AGRICULTURE

1. APPLICATIONS NEEDS

Agricultural resource managers need timely and accurate crop production estimates on which to base their decisions concerning management practices or policy. Inaccurate production estimates lead to economic and social impacts. At the individual farm level, farmers often have to decide whether or not to apply irrigation, pesticides, and fertilizers based on their assessment of crop production in their fields as well as the market condition. Planting dates and variety as well as crop type selection are based upon production expectations. At the regional and national level, government agriculturalists set policies that affect markets; these policies result in part from their knowledge of crop area and yield on a large area basis. The crops of principal interest are wheat, barley, corn, soybeans, sorghum, sunflowers, rice, and cotton. Remote sensing efforts are directed primarily toward the classification, area estimation, and condition assessment of these crops which occur with background land cover types such as bare fields, fallow fields, pasture, wooded, and cultural areas.

Before the advent of remote sensing, managers had to rely upon sparsely sampled information obtained from ground surveys. The quality and accuracy of such surveys vary widely from country to country (Hjort, 1974). Only a few countries have crop production estimation systems that meet even a minimum level of accuracy. Some report estimates only every 10 years. Some do not report at all. It is obvious that the ability of the current system is only fair and far from perfect or from that desired.

Crop production can be separated into two elements, area and yield, such that production equals area times yield. Remote sensing research has been conducted by the developed countries into the feasibility of improving the estimation crop area and yield through the use of images obtained from spacecraft systems. The vast bulk of the research has been centered around the image data obtained from the Landsat MSS. As is well known, the MSS operates in the reflected visible and reflected infrared region of the electromagnetic spectrum from 0.5 to 1.1 μm. Considerable research has also taken place on the TM sensor that operates from 0.45 to 2.7 μm. The TM also uses one thermal infrared band (near 10 μm). Studies of MSS data have shown utility in crop identification, area estimation, and crop canopy condition assessment. Direct indicators of canopy condition (e.g., leaf-area-index and biomass) and indirect indicators (e.g., bare soil wetness) from the MSS can be related to crop yield. However, much non-remotely sensed data are needed such as surface-based rainfall and temperature observations to complete yield forecasting procedures. Relatively low resolution meteorological satellite visible and infrared imagers acquired data that can be used to improve estimations of yield-related parameters such as rainfall amount and distribution and surface insolation. TM data should prove as useful as MSS data. Both systems operate in portions of the electromagnetic spectrum severely affected by the presence of liquid and ice water clouds in the atmosphere. The major basis for crop identification is the seasonal change exhibited by crops usually within fairly well defined times of the year. Thus, multidate MSS or TM data must be acquired frequently enough to allow detection of critical changes in crop growth. Separation of wheat, barley, and other small grains is difficult based on MSS data even when no acquisitions are lost due to clouds. Corn and soybeans show separability problems as well.

Once a field has been identified as to crop type, area may be estimated. Areal measurement accuracy is affected by the spatial resolution of the imaging system used as well as by the accuracy of labeling training data sets for the classifier. Also, once a field has been identified, spectral data may be indicative of crop or soil conditions that can be used in yield estimation.

2. MISSION REQUIREMENTS

Most research conducted to date on the microwave backscattering properties of crop canopies has been at frequencies above 8 GHz. This includes investigations at the University of Kansas with the (1-18 and 35 GHz) Microwave Active Spectrometer (MAS) systems (although the bulk of the work was concentrated on frequencies above 8 GHz in order to minimize backscatter contributions by the underlying soil surface), experiments at the University of Delft at 9 GHz; experiments at Paul Sabatier University, Toulouse, France, at 9 GHz, crop classification studies by the CCRS using a 13.3 GHz airborne scatterometer and by X- and L-band SAR's, and similar crop classification studies by the University of Kansas using the NASA/JSC 13.3 GHz airborne scatterometer and using the ERIM L-band SAR. Thus, at the L-band (~1.3 GHz) and C-band (~5.3 GHz) frequencies available for FIREX, a relatively small number of investigations have been conducted for crop applications, and most of those are at L-band. Recently, however, the University of Kansas has completed a preliminary analysis of C-band multidate data that were acquired by the NASA/JSC airborne scatterometer systems over a test site near Colby, Kansas in 1978. The results are very encouraging as they show that on some single-date missions, classification accuracies as high as near 80% range were obtained.

In 1978, seven missions were flown by the NASA C-130 aircraft over an agricultural test site near Colby, Kansas. Among the host of sensors flown were radar scatterometers that operated at L-, C-, and Ku-band frequencies. In conjunction with the airborne data, ground-truth information was collected for about 40 fields, although the scatterometer observations covered more than 150 fields. Using the 40 fields with available crop identifications as a guide, the remaining approximately 110 fields were identified by each of three independent photointerpreters on the basis of color infrared photography. If a field were identified by all three interpreters as belonging to the same cover-type, it was retained; otherwise, it was discarded. Because the photography was acquired from an altitude of 1,500 feet above the terrain, the identification process was fairly straightforward and resulted in only a few fields being discarded.

The C-band data acquired at 50° from nadir with HH polarization has been used to compute the classification accuracy for Flights 1 and 5. Flight 1, which was made on July 18, 1978, represents relatively dry soil moisture conditions, while Flight 5, made on August 8, 1978, represents relatively moist soil moisture conditions.

For data from each flight, the maximum likelihood classifier was used, once using the scattering coefficient values measured for individual pixels (each field contained 10-20 pixels, depending on size) and a second time using field-average values.

Table III-1 shows the classification results for Flight 1 in the form of a confusion matrix, on the basis of field-average scattering coefficient values. Table III-2 shows similar results on the basis of individual pixel values. The main observations made from these tables are:

(a) Corn can be separated from other covers with a high degree of accuracy, 92% for the field-average case (Table III-1).

(b) A fair amount of confusion exists between wheat stubble and fallow, which is not surprising.

(c) The overall correct classification accuracy is slightly higher for the field-average case (79.3%) than for the pixel case (75.5%), which is expected.

The results for Flight 5 are given in Tables III-3 and III-4. Again, corn is classified with a high degree of accuracy, but the confusion between wheat stubble and fallow is much worse. This is due to the influence of soil moisture which was higher for Flight 5 than for Flight 1.

TABLE III-1.- CROP CONFUSION MATRIX, MAXIMUM LIKELIHOOD CLASSIFIER, FIELD AVERAGE, C-BAND, HH, 50°, FLT. #1

Crop	Number of fields	Actual	Classified as			
			Corn	Pasture	Wheat stubble	Fallow
Corn	25	Corn	92.0	0	0	8.0
Pasture	17	Pasture	0	76.5	23.5	0
Wheat stubble	51	Wheat stubble	0	0	72.6	27.4
Fallow	52	Fallow	3.8	1.9	13.5	80.8
TOTAL	145					

Overall Accuracy = 79.3%

TABLE III-2.- CROP CONFUSION MATRIX, MAXIMUM LIKELIHOOD CLASSIFIER, PIXEL VALUE, C-BAND, HH, 50°, FLT. #1

Crop	Number of fields	Actual	Classified as			
			Corn	Pasture	Wheat stubble	Fallow
Corn	378	Corn	84.7	0	2.4	12.9
Pasture	218	Pasture	0	74.8	22.9	2.3
Wheat stubble	561	Wheat stubble	0.4	4.1	68.4	27.1
Fallow	626	Fallow	11.8	0.6	10.9	76.7
TOTAL	1,783					

Overall Accuracy: 75.5%

TABLE III-3.- CORN CONFUSION MATRIX, MAXIMUM LIKELIHOOD CLASSIFIER FIELD AVERAGE, C-BAND, HH, 50°, FLT. #5

Crop	Number of fields	Actual	Classified as			
			Corn	Pasture	Wheat stubble	Fallow
Corn	31	Corn	93.6	0	3.2	3.2
Pasture	17	Pasture	0	88.3	0	11.7
Wheat stubble	52	Wheat stubble	1.9	3.9	11.5	82.7
Fallow	54	Fallow	3.7	1.8	9.3	85.2
TOTAL	154					

Overall Accuracy = 62.3%

TABLE III-4.- CROP CONFUSION MATRIX, MAXIMUM LIKELIHOOD CLASSIFIER, PIXEL VALUE, C-BAND, HH, 50°, FLT. #5

Crop	Number of fields	Actual	Classified as			
			Corn	Pasture	Wheat stubble	Fallow
Corn	492	Corn	91.5	0.4	6.9	1.2
Pasture	219	Pasture	0.9	83.1	4.6	11.4
Wheat stubble	645	Wheat stubble	6.7	3.3	37.2	52.8
Fallow	638	Fallow	5.3	3.3	29.0	62.4
TOTAL	1,994					

Overall Accuracy = 63.7%

The results of similar analyses for K-band (13.3 GHz) data in the same experiment are shown in Table III-5 for comparison for Flight 1.

These preliminary results suggest that a C-band radar has the potential to provide good crop-classification results. Future analysis of the data under the AgRISTARS Supporting Research Project is expected to provide information on the crop-classification accuracy using (a) multi-date observations, (b) dual-polarization data, and (c) dual-frequency data (L-band data also were acquired for the same fields).

Continuation of the above study, in conjunction with the FIREX experimental program described in Section V of this document, should provide the basic answers regarding the capability of a C-band SAR (or C-band and L-band together) for monitoring agricultural crops.

a. Revisit Interval: Recommendation: < 10 Days

Single date radar data have been used for crop identification in several studies with only fair results. Using an L-band system (47° angle, HH or HV) over Huntington County, Indiana, in September 1973, Ulaby et al. (1980) obtained classification accuracies of 60-65% for corn, soybeans, wooded land, and pasture. In another study at 14.2 GHz, Ulaby et al. (1979) obtained classification accuracies from 45-69% for bare soil, corn, soybeans, sorghum, and wheat when the MAS 8-18 and one date were used. Results at 9 GHz were slightly worse. Using 13.3 GHz, Ulaby et al. (1981) classified an area having corn, fallow, bare soil, and pasture fields near Colby, Kansas, to an accuracy of from 61 to 71% when one date alone was used (see Table III-5).

TABLE III-5.- CROP CONFUSION MATRIX, LINEAR BAYES CLASSIFIER, PIXEL VALUE, K-BAND, VV, 50°, FLT. #1 (AFTER ULABY ET AL., 1981)

Crop	Number of fields	Actual	Classified as: Corn	Pasture	Wheat stubble	Fallow
Corn	143	Corn	70.0	0.0	3.6	26.3
Pasture	39	Pasture	0.0	86.6	13.3	0.0
Wheat stubble	156	Wheat stubble	1.6	19.1	70.8	8.3
Fallow	130	Fallow	19.0	0.0	13.0	68.0
TOTAL	468					

Overall Accuracy = 71.1%

Performance is similar to maximum likelihood classifier
Compare to Table III-2

Much improved classification results were obtained when multidate radar data were used. The addition of a second date produced increases in classification accuracy by from 13 to 40 percentage points, typically, a classification accuracy of around 90% was obtained after three visits. Bush and Ulaby (1977) specifically addressed the issue of revisit interval. Using the MAS 8-18, they found that increasing the revisit interval from 10 to 15 days significantly lowered the classification accuracy (10-15 percentage points). This is illustrated in figure III-1. There was not much difference observed between 5 and 10 days.

In another study, reported by Ulaby (1981) in which the multidate classification accuracy of radar and Landsat MSS - each alone and the two in combination - was investigated, the results show that radar was the prime sensor prior to wheat harvest and that the correct classification accuracy obtained was 95.6% after three visits (figure III-2) while Landsat was the prime sensor after wheat harvest with a classification accuracy of 84% after three visits (figure III-3). For this second period, the addition of radar to Landsat increased the accuracy to 91.6%. The question of the required revisit interval for crop identification cannot be settled by a few or one study. It must be resolved ultimately on the basis of studies of periodic satellite SAR data (which would be expensive for daily acquisition) or on the basis of simulation studies for many areas and situations.

b. Spatial Resolution: Recommendation: 30 m × 30 m (4 samples)

According to Landsat/MSS and related sensor studies (e.g., TM), spatial resolution can severely hamper classifiers since small fields will produce a significant number of boundary picture elements (pixels) where mixtures of land cover

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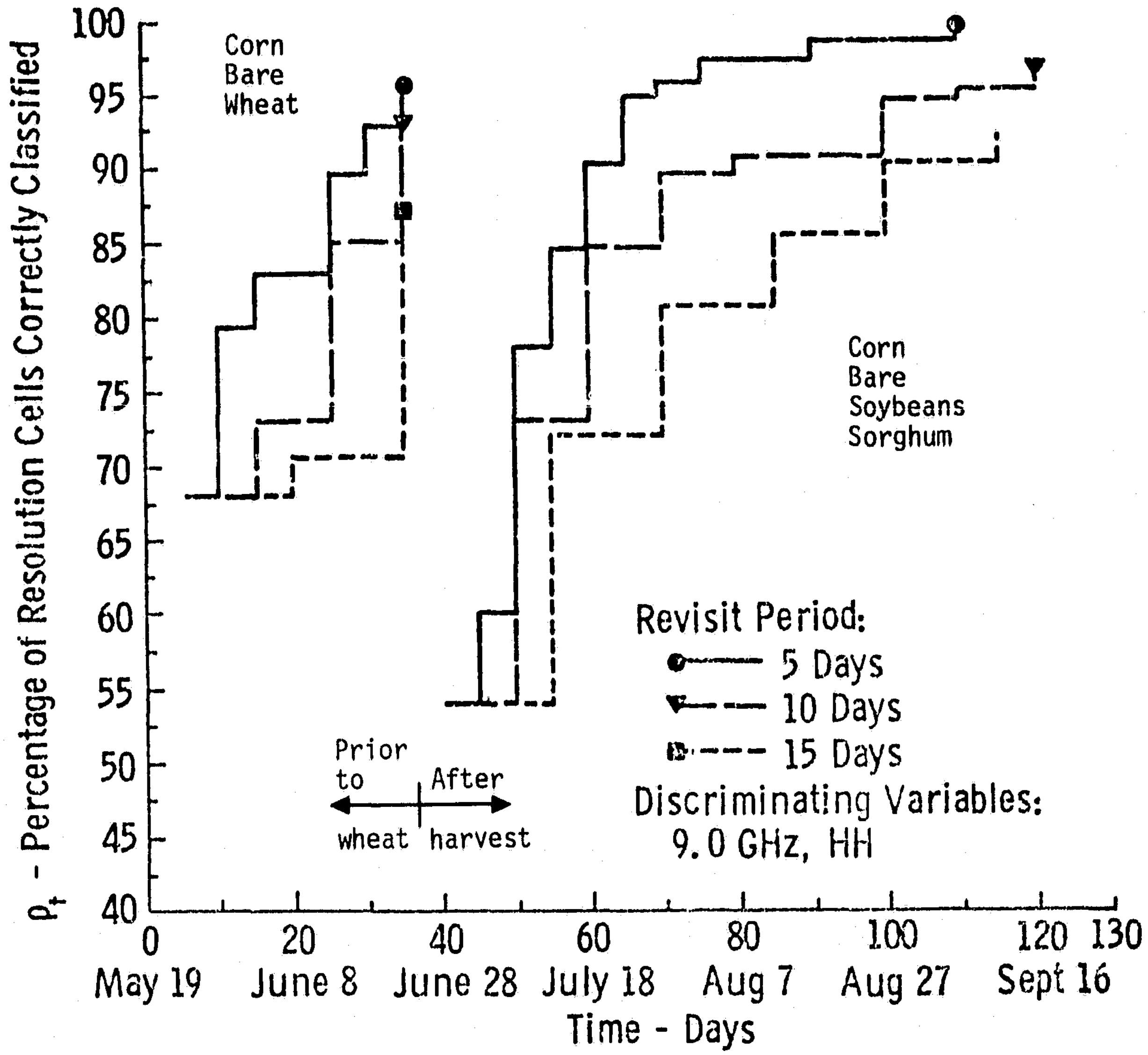

Figure III-1.- Variation of cumulative classification percentages with revisit period (9.0 GHz, HH). (After Bush and Ulaby, 1977).

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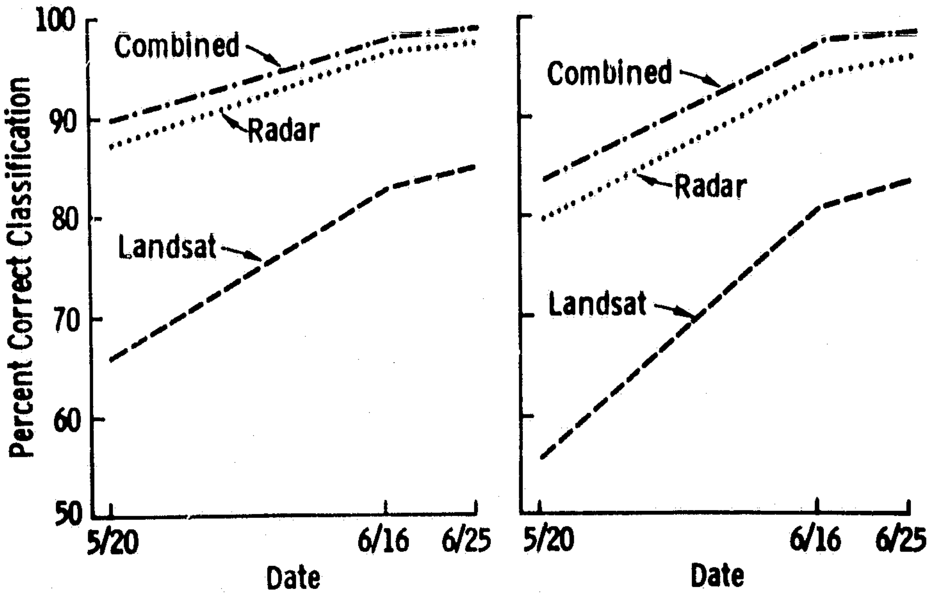
Date	5/20	6/16	6/25
	Percent Correct Classification		
Radar ·········			
All Classes	86.9	96.1	97.3
Crops	79.1	93.8	95.6
Landsat ----			
All Classes	65.6	82.4	85.1
Crops	55.4	80.4	83.4
Combined ·—·—·—			
All Classes	89.5	97.8	98.7
Crops	83.6	96.7	98.0



All Classes (Crops plus trees roads, water, and bare) Crops (corn, wheat, sorghum)

Figure III-2.- Classification--First Segment [Radar (14.2 GHz (HV, VV)) and/or Landsat (Bands 5 and 7)] (after Ulaby, 1981).

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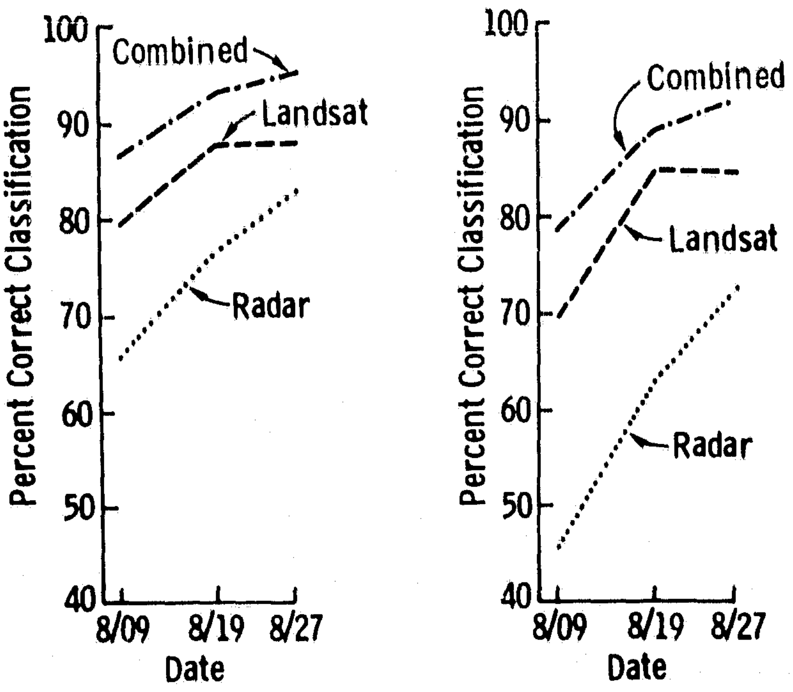
Date	Percent Correct Classification 8/09	8/19	8/27
Radar ········			
All Classes	65.7	76.5	82.5
Crops	45.5	62.6	72.2
Landsat ----			
All Classes	78.9	87.9	87.9
Crops	69.3	84.2	84.0
Combined -·-·-			
All Classes	86.4	92.8	94.7
Crops	78.4	88.6	91.6



All Classes (see figure III-2) Crops (see figure III-2)

Figure III-3.- Classification--Second Segment [Radar (14.2 GHz (HV, VV)) and/or Landsat (Bands 5 and 7)] (after Ulaby, 1981).

features exist. Pitts and Badhwar (1980) performed an analysis of field-size distributions in 133 5 × 6 n. mi. segments distributed randomly in the central states from Texas to North Dakota in two years. The model field size was near 10 acres for most crops (see figure III-4). Model field widths varied from 50-200 m due to strip fallow farming practices in many areas. The most interesting aspect of their study, however, had to do with an analysis of the proportions of pure pixels that would be expected for an imaging system for these same fields. The proportion of pure pixels is the number of pixels that would fall entirely within the boundaries of fields divided by the total pixels (pure plus boundary or mixed pixels). Figure III-5 shows the results of this analysis clearly for wheat, corn, and soybean fields. Note, for example, that the proportion is only 35-40% for Landsat/MSS pixel size (80 m). The accurate classification of mixed pixels has not been accomplished and is a major problem in current Landsat/MSS applications. At 30 m pixel size (as recommended for the Landsat/TM and for the SAR in their study), 72-76% of the pixels would be pure.

In radar imagery, both resolution and the number of independent samples contained in a resolution element have to be considered to account for the effects of signal fading (i.e., radar speckle). It is the opinion of the Renewable Resources Study Team that a 30 m × 30 m resolution element with 4 independent samples (4 along track azimuth looks and one across track look) is the best practical spatial resolution obtainable for SAR. For a system with a ground range resolution of 30 m, this corresponds to a single look resolution of 7.5 m (azimuth) × 30 m (range).

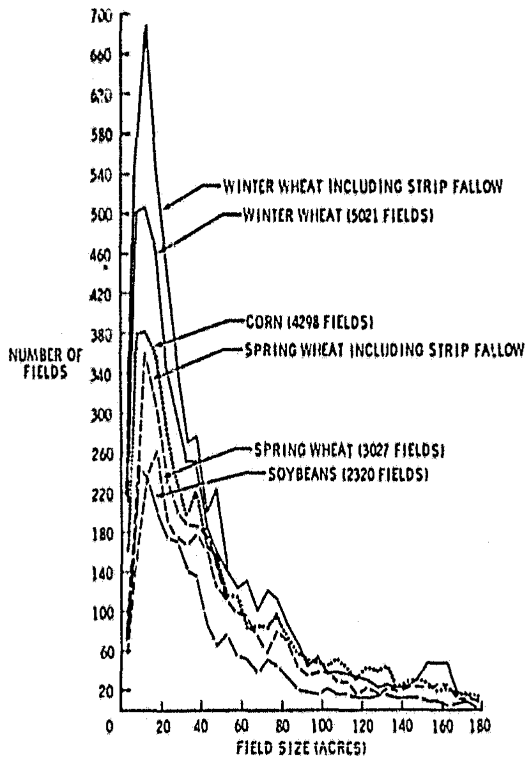


Figure III-4.- Field size distribution for wheat, corn, and soybeans. (After Pitts and Badhwar, 1980).

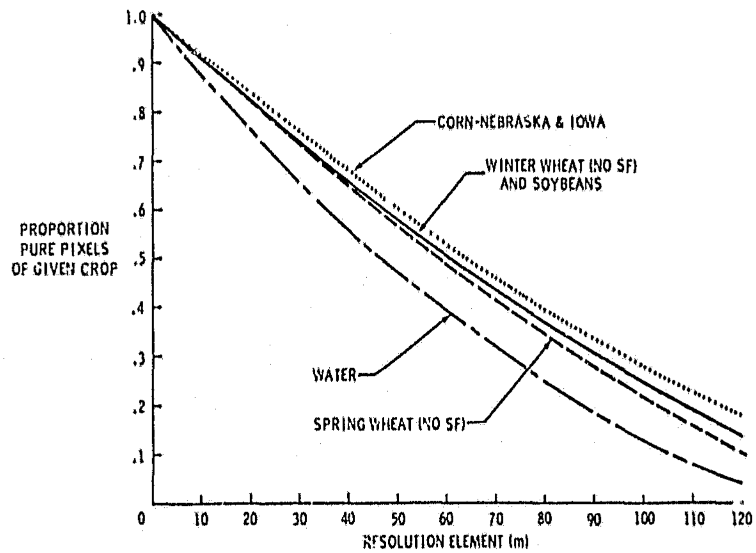


Figure III-5.- Proportion of a crop in pure pixels as a function of sensor resolution. (After Pitts and Badhwar, 1980).

c. Incidence Angle: Recommendation 45-60° r

The specification of the best incidence angle for crop applications is made difficult by the fact that few studies have been conducted at C-band. Limited studies conducted in the 8-18 GHz range and at multiple angles of incidence showed that 50° was optimum (Bush et al., 1975; Ulaby and Bush, 1975). At these high angles, the radar backscatter is dominated by the water suspended in the vegetation canopy, as shown, for example, in figure III-6 for 17 GHz, 50° data from corn. A correlation coefficient of 0.962 was found between the radar backscatter coefficient and the corn water man per unit volume. A key research objective for the FIREX mission is to determine if similar strong relationships exist for C-band data at high incidence angles. Preliminary results of C-band airborne scatterometer data show that crop classification accuracy improves with angle of incidence up to 50° and then decreases slightly (by 4 percentage points) at 60°.

Due to the limited number of previous studies on the question of the optimum angle of viewing for a C-band radar, the Renewable Resources Study Team recommends that this question be addressed specifically by the experimental research program defined in Section V below.

d. Frequency and Polarization Combination: Recommendation: (Prime) C-band VV; (Acceptable) C-band HH

Higher frequencies (i.e., C-band rather than L-band) are preferred for crop identification and canopy condition assessment since L-band radiation penetrates crop canopies with little interaction. Incidentally, interaction at L-band with forest canopies may be significant. Large incidence angles are required also so

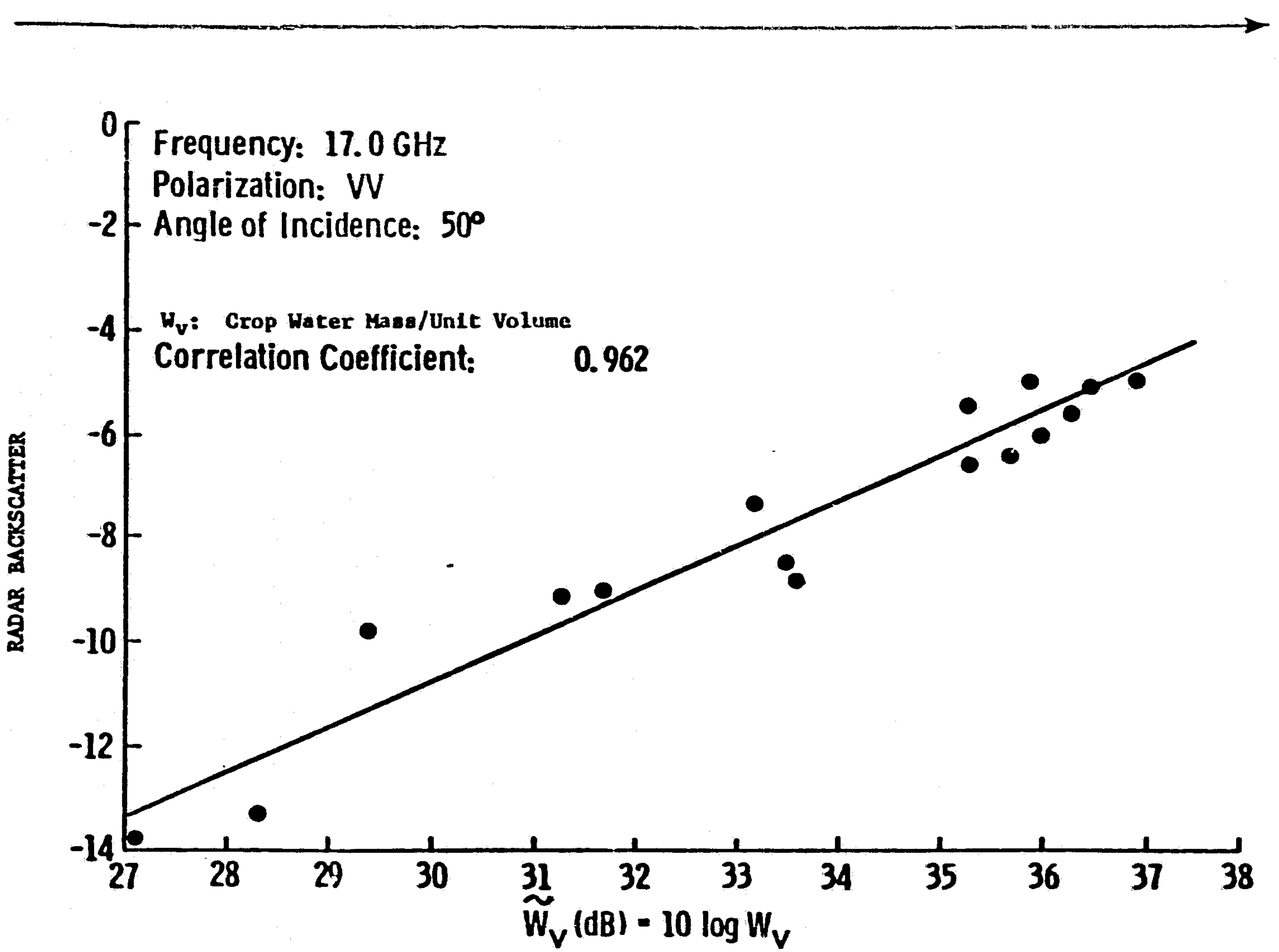


Figure III-6.- Relation between radar backscatter from corn and its water content (mass per unit volume). (After Ulaby and Bush, 1975).

that the path length through the canopy is sufficient to produce significant backscattering from the canopy as compared to that from the surface soil. As stated above, most studies have resulted in X-band or Ku-band (~13 GHz) being selected over L-band or C-band. There is really no question that C-band will produce better results than L-band; but, it is not known how satisfactory the results will be at C-band as compared to X-band and higher frequencies.

The best single-frequency configurations have usually been with VV polarization (Bush and Ulaby, 1977; Ulaby et al. 1979; Bush et al., 1975; Ulaby and Moore, 1973). Results using HH are usually only slightly worse than results using VV.

e. Improvement Afforded by Multifrequency or Multipolarization

Past studies of the improved performance of dual frequency and dual polarization (like and cross) have shown significant increases in classification accuracy; however, the dual frequencies involved have always been in the 8-18 GHz range, a range not being considered for the FIREX system. Thus, the improvement to be expected from the use of L-band and C-band has not been studied in the past. Theoretically, C-band returns should be affected significantly by surface condition (roughness, moisture, row structure). Thus, it seems logical to assume that multifrequency or multiangle data will be needed to sort out canopy and soil surface effects. These effects are better separated when X-band and K-band is used (Attema and Ulaby, 1976). Thus, the improvement that might be seen in crop classification accuracies as the result of C-band and L-band or of dual-polarization C-band should be a specific research issue to be addressed by the experimental program plan below in Section V.

So far as the usefulness of like- and cross-polarization data for crop identification is concerned, a few studies conducted in the 8-18 GHz range have shown improvements in classification accuracies of only 1-6 percentage points (Ulaby et al., 1980; Ulaby et al, 1979). However, cross polarization has been found to be very useful in separating vegetation-covered areas from bare surfaces. Thus, the potential improvement derived from the availability of cross-polarized data should be evaluated for scenes containing a variety of land categories. This issue should be specifically addressed by the experimental research program in Section V below.

f. Role of FIREX System as Compared to the MSS and TM

After years of study by hundreds of investigators, the information content of single date MSS data so far as crop canopy or soils data are concerned can be reduced to two basic parameters -- soil brightness index (SBI) and green vegetation index (GVI) given as follows (Kauth and Thomas, 1976):

$$SBI = 0.43\ MSS4 + 0.63\ MSS5 + 0.59\ MSS6 + 0.26\ MSS7$$

and

$$GVI = -0.238\ MSS4 - 0.66\ MSS5 + 0.577\ MSS6 + 0.381\ MSS7$$

Investigators have related SBI and GVI to other parameters such as bare soil moisture content at the surface, green leaf area index and green biomass. The multidate sequence of changes in GVI or greenness has been used to identify crop type (Badhwar, 1979) and to estimate crop stage of development (Badhwar and Henderson, 1980).

The limited investigations of radar data, most of which are obtained from truck- or aircraft-based systems over limited areas and dates, have shown that radar backscattering responds mostly to the canopy moisture content which is related to green biomass or green leaf area index. It is not known whether or not a radar green vegetation index, GVIR, can be defined from radar data; but, the prospect is good. If so, then GVIR estimates might be substituted for GVI when clouds prevent Landsat/MSS or TM data acquisition of surface informations. Thus, the combined use of radar and MSS or TM could be profitable. Ulaby and his collaborators have established that the combined uses of X-band or K-band data with MSS data produces significant improvements (~10 percentage points) as compared to either alone (Li et al., 1980)

It has been established also that radar data acquired at small incidence angles contains information about surface soil moisture (Bradley and Ulaby, 1981). SBI is affected by soil moisture also; thus, a link may exist between radar and MSS so far as soil properties are concerned.

Thus, the radar and visible/infrared may respond to related soil and crop canopy parameters, but in a strict technical sense, they respond to different parameters -- radar to canopy moisture content and perhaps to canopy morphology as well as to surface soil moisture and MSS to leaf area index, green biomass, and soil type and moisture in a shallower depth than radar.

g. Miscellaneous Specifications

The Renewable Resources Study Team specified that the multidate repeatability accuracy of a FIREX system be 1 dB or less. This is due to the relatively small range in $\sigma°$'s that may result even over the growing season for crops. Past studies cited above have shown that the difference in $\sigma°$ for various crop types is usually no more than 10 dB. Also, the total range of $\sigma°$ over a growing season has been observed to be as small as 2 dB and as large as 10 dB. This places a severe requirement on SAR calibration and repeatability.

If multisensor (multidate, multifrequency, radar plus MSS or TM, multiangle) data sets are needed, then registration of the various radar images must be accurate to less than the size of one pixel. Unregistered data will result in data sets that can exhibit strange $\sigma°$ patterns since two or more targets may be viewed as one with the resulting confusion.

An important mission requirement is the time of sensor overpass. The preferred times are 1300-1600 and 0100-0400 local times. These times represent the extremes of canopy and soil moisture contents. In fact, multitemporal data (taken twice a day) may be used for crop stress and surface moisture content determinations in a way different than single time-of-day data.

3. RESEARCH ISSUES

The specific research issues of concern to the agricultural part of the Renewable Resources Mission Requirements for the FIREX system are as follows:

a. Incidence angle effects: What is the loss or gain in expected performance of a SAR system due to changes in incidence angle over the range of 45-60° so far as crop identification, area estimation, and canopy condition assessment are concerned? This issue needs to be resolved for multidate L-band data and multidate C-band data for like- and cross-polarization for early, mid, and late season estimates for several major crop types such as small grains (wheat, barley, sunflower, oats), corn, and soybeans.

b. Improvement offered by multifrequency: What is the gain in expected performance of a SAR system due to the addition of L-band to a C-band configuration so far as crop identification, area estimation, and canopy condition assessment are concerned? This issue needs to be resolved for multidate data for like- and cross-polarization for early, mid, and late season estimates for several major crop types. The tradeoff in this case is the marginal cost of a dual frequency system as compared to a single frequency system.

c. Improvement offered by multipolarization: What is the gain in expected performance of a SAR system due to the addition of cross-polarization to a baseline like polarization configuration so far as crop identification, area estimation, and canopy condition assessment are concerned? This issue needs to be resolved for multidate data for early, mid, and late season estimates for several major crop types. The tradeoff in this case again is the cost of a dual polarization system as compared to a like polarization system.

B. SOIL MOISTURE MAPPING

1. APPLICATIONS NEEDS

The spatial and temporal distributions of soil moisture content represent a key input parameter to meteorological, hydrological and crop growth development and yield models. Although all of these are economically important application areas, only the crop yield estimation problem will be discussed in this section, merely to illustrate the significance of soil moisture information.

Experimental investigations have shown that vegetation growth and yield are driven by many interacting variables (table III-6). It is necessary to think in terms of different models for each crop species, rather than a generalized model which will fit all crops. The degree of detail required for a specified model is determined primarily by the amount and accuracy of the data available and by the degree of precision necessary in the end product. However, even very simplistic models can be quite useful. For example, Thompson (1969) developed a wheat yield model which relies largely on temperature and precipitation records. It has been used successfully with Landsat/MSS imagery to achieve estimates for Kansas wheat yields within 5% of the official Statistical Reporting Service (SRS) figures for the same Kansas counties (Morain and Williams, 1975). The SRS itself uses a very sophisticated model which utilizes four variables--the crop's condition at the time of the estimate, the previous two months' precipitation, the predicted precipitation for the following two months, and the length of time between the estimate and the harvest date. Yield models that use estimated soil moisture (e.g., from a water balance model) perform better than those that use rainfall directly (Idso, Jackson, and Reginato, 1975).

Of the pertinent factors required for modeling and forecasting yield, fluctuations of water availability and uncertainty in the knowledge of water availability are the most significant obstacles to obtaining the desired forecasting accuracy. Direct acquisition of soil moisture information on a large area basis is not possible at the present time. This has forced modelers to use precipitation data from meteorological stations in conjunction with a water budget model to estimate soil moisture content by accounting for infiltration,

TABLE III-6.- FACTORS INFLUENCING CROP GROWTH (AFTER MILTHORPE AND MOOREBY, 1974)

(a) Aerial environment

1. Mean day and night temperatures.
2. Total amount of visible radiation in each photoperiod.
3. Total net radiation in each photo- and dark-period.
4. Length of photoperiod.
5. Profile of visible radiation through crop canopy.
6. Profile of net radiation through crop canopy.
7. Profile of dry bulb temperature through crop canopy.
8. Profile of water vapour content of air through crop canopy.
9. Daily wind run.
10. Rainfall.

(b) Soil environment

1. Amounts of water in soil layers at the start of simulation.
2. Soil water content at wilting point ($= -1500$ J kg^{-1}) and field capacity (≈ -10 J kg^{-1}) in each of the soil layers.
3. Amounts of available N and P in each soil layer at the start of simulation.
4. Temperature profile through soil.
5. Rates of fixation and release of N and P in soil.

(c) Crop characteristics

1. Dry weights of meristems in seed and of stem, leaf and root primordia at some predetermined stage of growth considered to be time of initiation.
2. Number of seeds per unit area.
3. Relative concentrations of photosynthate, N and P in meristematic tissues and the change in these concentrations as the tissues age.
4. Values of constants in logistic equations used to describe growth and variations in growth or organ with temperature.
5. The weight of leaf primordia in dicotyledonous plants at unfolding from apical bud or the fractional size of monocotyledonous leaves at emergence from the next older leaf sheath.
6. Size of root members at branching and rate of production of branches.
7. Proportionality factors relating leaf weight to area, internode weight to length, and root length to weight.
8. Amounts of reserve materials required in pool for start of branch growth.
9. Requirements for onset of flowering.

runoff, evaporation, and transpiration. Such an approach automatically is burdened with the poor accuracy associated with estimating precipitation through extrapolation between meteorological stations.

Physiological yield models that use by soil moisture data at localized instrumented sites have shown encouraging success in forecasting yield (Kanemasu and Lawlor, 1980; Pitter, 1977; Bridge, 1976; Baier and Robertson, 1968; Albrecht, 1971; Baier, 1973). These types of geographically limited experiments have provided a basis for hypothesizing the needs for soil moisture as follows:

1. Spatial resolution of 100-1000 meters is desirable for yield models of agricultural crops and for minimizing errors due to cultural features.
2. Soil moisture in terms of field capacity and field capacity in terms of absolute usable moisture content. The number of levels is to be determined through sensitivity analyses and test of yield models. The separation of levels will probably not be equal but closer spaced for lower soil moisture levels. Tentatively, levels that would be within ±10% of the actual value from the wilting point to field capacity appear reasonable. However, the levels required for providing adequate input into soil moisture budget models to achieve the required yield forecasting accuracy can be determined only when used with yield models.
3. The depth of soil moisture information needed differs with application. First, at seed bed preparation time, a near surface profile of soil moisture in the first 10 cm layer would be useful to determine seeding conditions, germination probability and initial conditions for soil moisture budget models. Second, a profile to about 150 cm (less in some soil systems and greater in others) is needed for bare fields with a soil moisture value

every 10 to 30 cm. This could be used to initialize soil moisture budget models also. Third, surface zone soil moisture under a developing canopy would help determine the number of moist degree days, useful for wheat in estimating the number of tillers and heads which will be produced, and hence for estimating potential yield (Black, 1970).

It is important to note that the period of time during which soil moisture exerts the greatest effect on adventitious root formation is very short; in Montana, most adventitious roots develop during the month of May (Black, 1970). These roots, which develop from the tillers or lateral shoots of the wheat plant, increase the likelihood that the tillers will become independent, grain-producing shoots and also increase the resistance of the entire plant to adverse moisture conditions. While exact time of adventitious root formation may vary with latitude or other geographical variables, the critical stage of morphological development will most likely always be relatively short.

All of the depths mentioned above are unachievable using a remote measurement directly. Combined with soil moisture budget models, it is possible that soil moisture measurements in the top 0-5 cm could be used to interpolate precipitation measurements to locations between weather stations so that areal average rainfall estimates are improved. However, the shallower the measurement, the more critical will be diurnal adjustments of results and selection of overpass time. In addition, since only the top few centimeters of the soil appear to be controlling the radar response, then frequent (1-3 days) measurements with an appropriate evapotranspiration/percolation model will be required to provide a statistical method for determining plant stress. As the soil moisture yield investigations have not been conducted and tested over large areas, the above requirements may be revised. Iterative testing and information extraction upgrading will most probably be required to obtain the best results.

Excess soil salinity occurs in many arid and semi-arid areas of the world due to increasingly saline water tables resulting from both changing land use patterns and improper irrigation practices. Major regions of irrigated agriculture in the U.S. (e.g., the Coachella Valley in California or the lower Rio Grande Valley in Texas) suffer from the buildup of salts resulting from the upward transport of saline ground water and associated evapotranspiration at the surface. In these regions, it is necessary to map and to monitor salinity levels in the top few centimeters of soil in order to plan irrigation schedules and to advise area farmers on optimal planting and crop rotation practices. In addition, in the Northern Great Plains of the U.S. and southern Canada, current cropping-fallowing practices coupled with a natural tendency toward accumulation of excessive salts in discharge or seep ponds, have led to an exacerbated problem of saline seeps which have caused very substantial economic losses. This area is shown in Figure III-7.

It is estimated (Miller and Bahls, 1976; Horton et al., 1977; Bahls and Miller, 1973) that the areas affected in the northern U.S. were (respectively) Montana (225,000 acres), North Dakota (125,000), and South Dakota (67,500)--an area totalling 417,500 acres. The potential area capable of being damaged in the U.S. was some 40 million acres with another 120 million acres in the Prairie Provinces of Canada (Alberta, Manitoba, and Saskatchewan). The significance of this problem is seen when it is noted that the losses in the U.S. over about

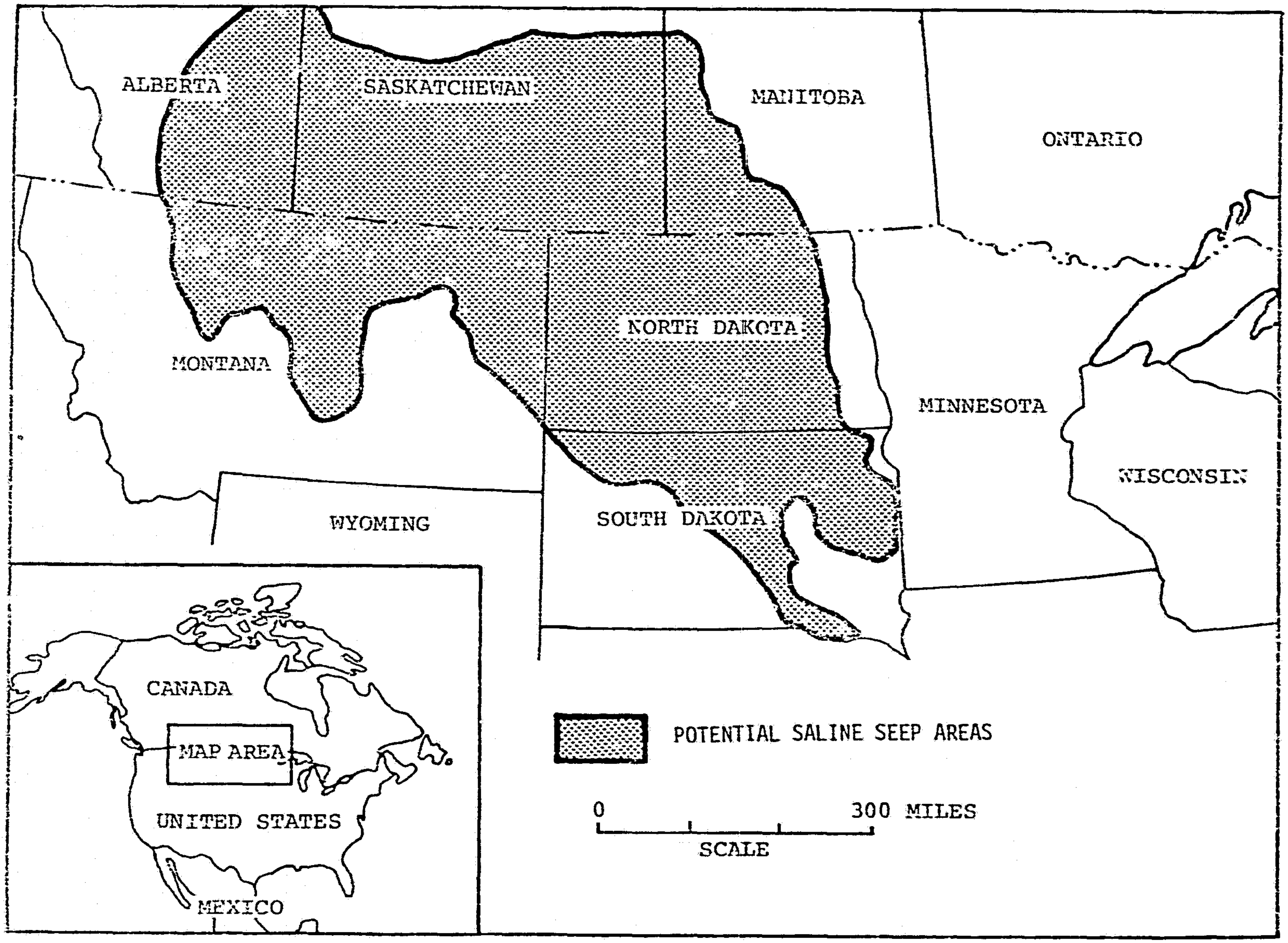


Figure III-7.- Potential saline seep areas in the Northern Great Plains and Canadian Prairie Provinces.

the last decade -- as the problem became apparent -- has totaled $100 million, the yearly increase in abandoned land is another $10 million, and the annual loss in crop income from reduced yield is $2.4 million.

In the case of saline seeps, the solution to the problem requires pumping out the water from a potential discharge zone before the salt accumulation becomes so great that plant growth is stunted or halted. There are basically two ways of accomplishing this: (1) by deep plowing the soil, thus redistributing the salts over a larger soil volume, and (2) by planting a deep-rooted crop such as alfalfa which can pump out the water while tolerating an early increase in salt content which would normally decimate small grains. In either procedure, it is necessary to detect the formation of a saline seep while it is in the very early stages, i.e., means for remotely sensing and mapping potential seeps are required.

Microwave sensors are ideally suited to this task of remotely detecting both an increase in ponded subsurface water and an increase in electrical conductivity caused by the potential seep. Distilled water has a dielectric constant of about 80 in the L-band to C-band range, whereas dry soil has a dielectric constant of about 3 at this range. Thus, soil-water mixtures exhibit a wide range of dielectric constants; thus, a radar backscatter that is strongly sensitive to moisture content. As salts are added to the soil-water mixture, the imaginary part of the dielectric constant at L-band again changes markedly because of the chemical combination of the salt and water molecules which in turn releases highly mobile conducting ions and electrons. In effect, the salt water-soil mixture behaves as a weak conductor, whose effective conductivity increases with decreasing frequency. Thus, for the same spatial resolution, an L-band radar would be more sensitive to soil salinity than a C-band radar, which would in turn be more sensitive that an X-band radar.

This theoretical trend was predicted by Carver (1977) and confirmed experimentally by him in a 1978 remote sensing investigation of a distribution of saline seeps in Harding County, South Dakota (Carver and Bush, 1979). Using both active and passive airborne C-130 microwave sensors and an extensive set of ground truth (soil moisture, soil salinity, surface roughness and vegetation cover) over a 200 m × 200 m site, it was found that when the soil was wet, the L-band radar showed a σ° increase of nearly 20 dB at an incidence angle of 20° when a fully developed saline seep was compared to background soil with normal salinity and winter wheat cover (see figure III-8). An increase of about 12 dB at 15° was noted at C-band, using the C-130 scatterometers. As expected, the L-band and C-band radiometric brightness temperature showed a pronounced decrease over the seeped zones. In this experiment, the average volumetric soil moisture was about 25%, as a result of a period of several days rain preceding the June 3, 1978, overflight by the C-130. If the surface were dry, the ions associated with the surface salts could not go into solution so that no appreciable signature would be expected for a saline seep. As an example, the only SEASAT SAR (L-band, 20°) pass over this area was on August 12, 1978, over 2 months after the C-130 overflight and early June rains. This data was digitally processed into image form by JPL and carefully analyzed for expressions of salinity. None was found due to the very dry soil at the time of the SEASAT SAR overpass. The June 1978 saline seep experiment in Harding County, South Dakota, was very encouraging since it suggested that an L-band 20° imaging radar would

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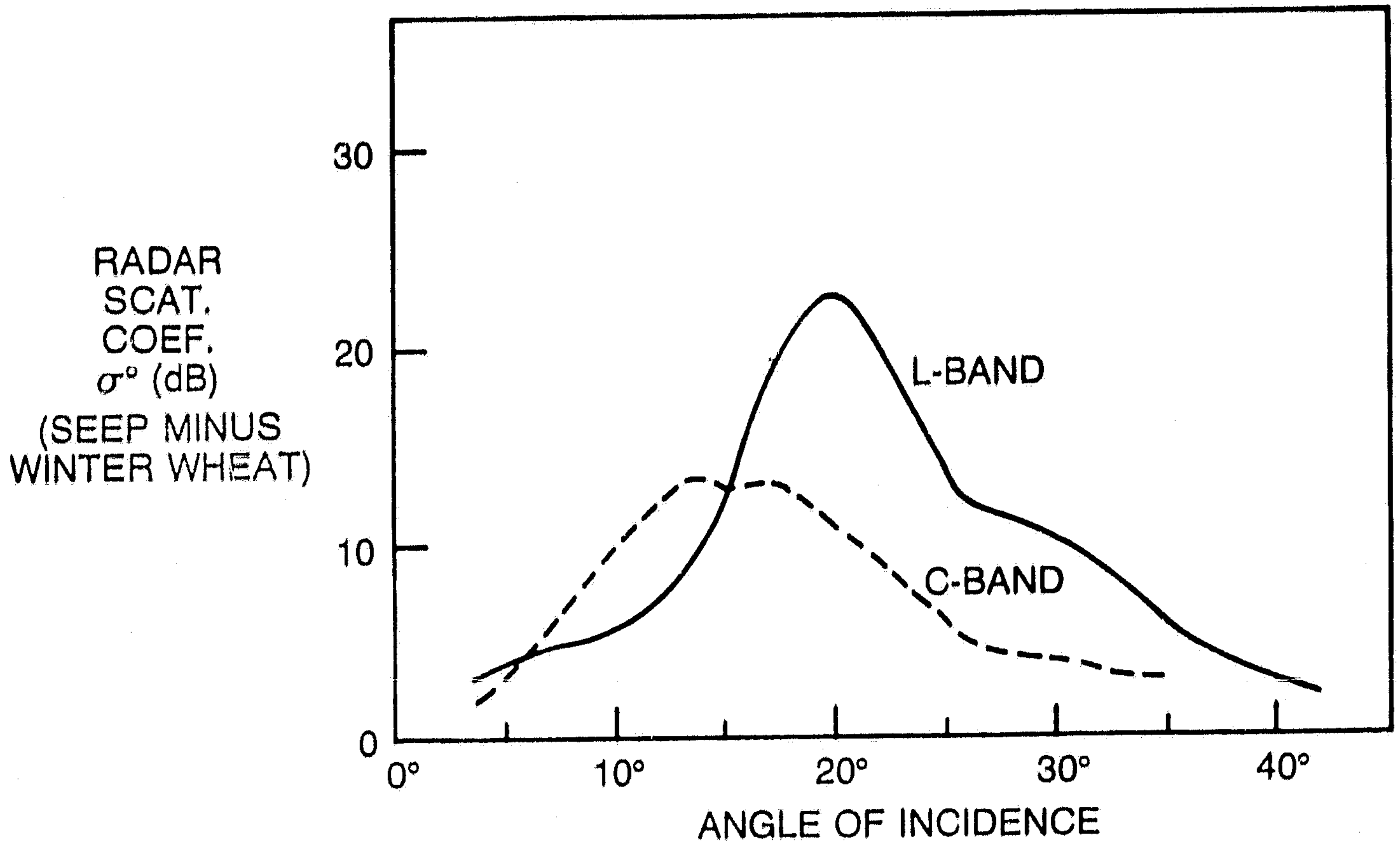

Figure III-8.- Saline seep effects on radar backscatter.

be an ideal remote sensor to map both fully developed and potential seeps when data were acquired after a rainfall. Nonetheless, the experiment was site- and time-specific and it was apparent that the trend needed to be confirmed.

In 1981 (at this writing), a second saline seep experiment is being performed at both the Harding County site and also two larger sites in Montana (Rapelje and Highwood Bench). The results of this experiment are not yet known.

Additional experiments should also be performed at Canadian sites in Saskatchewan, Alberta, and Manitoba where extensive soil salinity is also found, due to the same combination of surficial geology, soil types, and drainage patterns.

2. MISSION REQUIREMENTS

Table III-7 provides a summary of the major studies reported in the literature that pertain to radar backscatter from soil surfaces. These studies were conducted to investigate the potential for using remote sensing to make direct measurements of soil moisture conditions from aircraft or spacecraft platforms. NASA has made a major investment of research resources into the area over the last decade in such projects as the Joint Soil Moisture Experiment, the Agricultural Soil Moisture Experiment, the AgRISTARS Soil Moisture Project, and the Plan of Research for Integrated Soil Moisture Studies. As a result, much is known about the ability of remote sensing for soil moisture measurement. An important area being worked now is the question of what procedures could be employed to use periodic remote sensed soil moisture (which is limited to the upper few centimeters of soil) for several agricultural and hydrological

TABLE III-7.- SUMMARY OF ACTIVE MICROWAVE INVESTIGATIONS OF SOIL MOISTURE AND RELATED SCENE VARIABLES

Platform	Soil Cover	Frequency GHz	Angular Range (Degrees)	Polarization(s)	Institution	Year Reported	Reference	Major Emphasis of Investigations and Comments
Truck	Bare	4-8	0-70	HH, VV	U. of Kansas	1974	[1,2]	Surface roughness
Truck	Bare	2-8	0-40	HH, VV	U. of Kansas	1976	[3]	Surface roughness, Miller clay soil
Truck	Bare	1-8	0-30	HH, VV, HV	U. of Kansas	1978	[4]	Surface roughness, Eudora silt loam soil
Truck	Bare	1-8	10-20	HH, VV, HV	U. of Kansas	1981	[5]	Soil type
Tower	Bare	9	10-80	HH, VV, HV	U. of Delft (Netherlands)	1979	[6]	Surface roughness
Tower	Bare	1.5,3,4.5,9	10-80	HH, VV	Inst. Nat'l. Agronomique (France)	1979	[7]	Surface roughness
Tower	Bare	1.5,3,4.5,9	0-70	HH, VV, HV	U. Paul Sabatier (France)	1980	[8]	Surface roughness
Car	Bare	9	30	HH, HV	U. of Tokyo (Japan)	1978	[9]	Surface roughness, low density soil
Truck & Aircraft	Bare	1.6,4.75,13.3	5-50	HH, VV, HV VV only for 13.3	NASA/JSC	1980	[10]	Row direction (of large-scale periodic patterns)
Truck	Vegetation	4-8	0-70	HH, VV, HV	U. of Kansas	1975	[11]	Masking by vegetation cover
Truck	Vegetation	8-18	0-70	HH, VV, HV	U. of Kansas	1975	[12]	Masking by vegetation cover
Truck	Vegetation	1-18	0-70	HH, VV, HV	U. of Kansas	1979	[13]	Row direction
Truck	Vegetation	1-8	0-50	HH, VV, HV	U. of Kansas	1979	[14]	Masking by vegetation
Aircraft	Bare and Vegetation	0.4,13.3	5-60	VV	U. of Kansas	1974	[15]	Differentiation between dry and irrigated fields
Aircraft	Bare	1.6, 13.3	5-40	HH, HV(1.6) VV(13.3)	Texas A & M U.	1978	[16]	Multi-date flights
Aircraft	Watersheds	0.4,1.6,4.75	5-50	HH	USDA/NASA/GSFC	1980	[17]	Multi-date flights
Aircraft	Bare and Vegetation	1.6,4.75,13.3	5-50	HH, VV, HV VV only for 13.3	U. of Kansas	1980	[18]	Soil moisture response for large number of fields
Skylab	Bare and Vegetation	13.9	30	VV	U. of Kansas	1974	[19]	IFOV = 200 km^2
Seasat	Bare and Vegetation	1.3	20	HH	Texas A & M U	1981	[20]	Multi-date passes, report in writing stage

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applications as listed in Table III-8. These potential applications are ranked subjectively by degree of difficulty.

Also, the items in Table III-8 are labeled as direct applications where only surface zone soil moisture data are needed and as indirect applications where deep zone (root zone) soil moisture estimates are needed based on the remote sensed direct measurements and models to predict gains and losses of water in a deep zone.

a. Revisit Interval: Recommendation: < 10 Days [r]

The specification of revisit interval, swath width and amount of surface coverage by multidate passes by a satellite SAR is dependent upon the requirements of specific procedures for using remote sensed soil moisture measurements. It appears that most applications would need a revisit interval of about one day. This is an issue for research. As a research satellite, the SAR revisit interval can be as little as 10 days. In this configuration, however, only the ability of such a SAR system to make direct measurements of surface soil moisture condition could be evaluated. The eventual specification of the maximum acceptable revisit interval for surface soil moisture measurements for a future operational satellite SAR system could be made on the basis of carefully planned and conducted experiments using ground-based systems or aircraft-based systems alone.

b. Spatial Resolution: Recommendation: 300 m (4 samples) [r]:

Ulaby et al. (1981) has made a study of the effects of spatial resolution on the ability of a C-band HH SAR (incidence angle of 10-20°) to produce data that can

TABLE III-8.- POTENTIAL APPLICATIONS FOR REMOTE SENSED SOIL MOISTURE MEASUREMENTS

Ranking (based on degree of difficulty)	Potential application
1	Measurement of surface layer soil moisture condition (few direct applications, see 2 below)
2	Seed germination success estimation (surface zone)
2	Rainfall (gage) data interpolation and areal mean estimation (surface zone)
2	Planting date estimation (surface zone: effects of wet ground on farming operations)
3	Infiltration rate estimation (surface zone)
3	Surface evaporation estimation (surface zone: important in bare fields and early season before transpiration becomes dominant water loss process)
4	Root zone soil moisture content estimation (deep zone: cannot be monitored directly by remote sensing; but may be estimated through modeling of water gain and loss processes)
5	Water use (cumulative evapotranspiration) by crops (deep zone)
5	Crop stage-of-development estimation (deep zone)
5	Crop growth (biomass production) estimation (deep zone)
5	Crop grain yield estimation (deep zone)
5	Runoff estimation (deep zone) for flood and water resources applications

be used to estimate surface-zone soil moisture. As spatial resolution size is increased, speckle (caused by fading) is reduced in the image; but, increased interpretation problems will exist due to mixing soil areas with non-soil areas (urban, water, forests) within the same pixel. The best results were obtained when the spatial resolution was on the order of 100-1000 m (see figure III-9). Since the study was based on simulation by computer, the validity of the results are dependent upon the validity of the simulation model. The University of Kansas is under NASA contract in the AgRISTARS Soil Moisture Project to improve the reality of the simulation models by introducing evaporation and transpiration variations from field to field and by introducing between field and within field variations in crop biomass. For this reason, the specification of spatial resolution is flagged as a research issue.

c. Incidence angle, Frequency, and Polarization: Recommendation: C-band HH 10-20° r

To minimize the effects of surface roughness and of vegetation cover on the radar response to soil moisture, angles below 30° and preferably below 20° should be used. In the absence of periodic row patterns, the C-band 20° HH configuration appears to provide optimum performance with regard to sensing soil moisture content for both, bare and crop-covered soil. On the average, the moisture being sensed is that contained in the top 5 cm layer or less, and the moisture content is best expressed as percent of field capacity of that layer (to minimize dependence on soil texture). These results are based on experiments by the University of Kansas (figure III-10), Le Toan et al. (1980) of Paul Sabatier University in France (figure III-11), Jackson et al. (1981) of USDA and NASA/GSFC, and Bernard et al., (1981) of the Center for Physical Research of the Terrestrial and

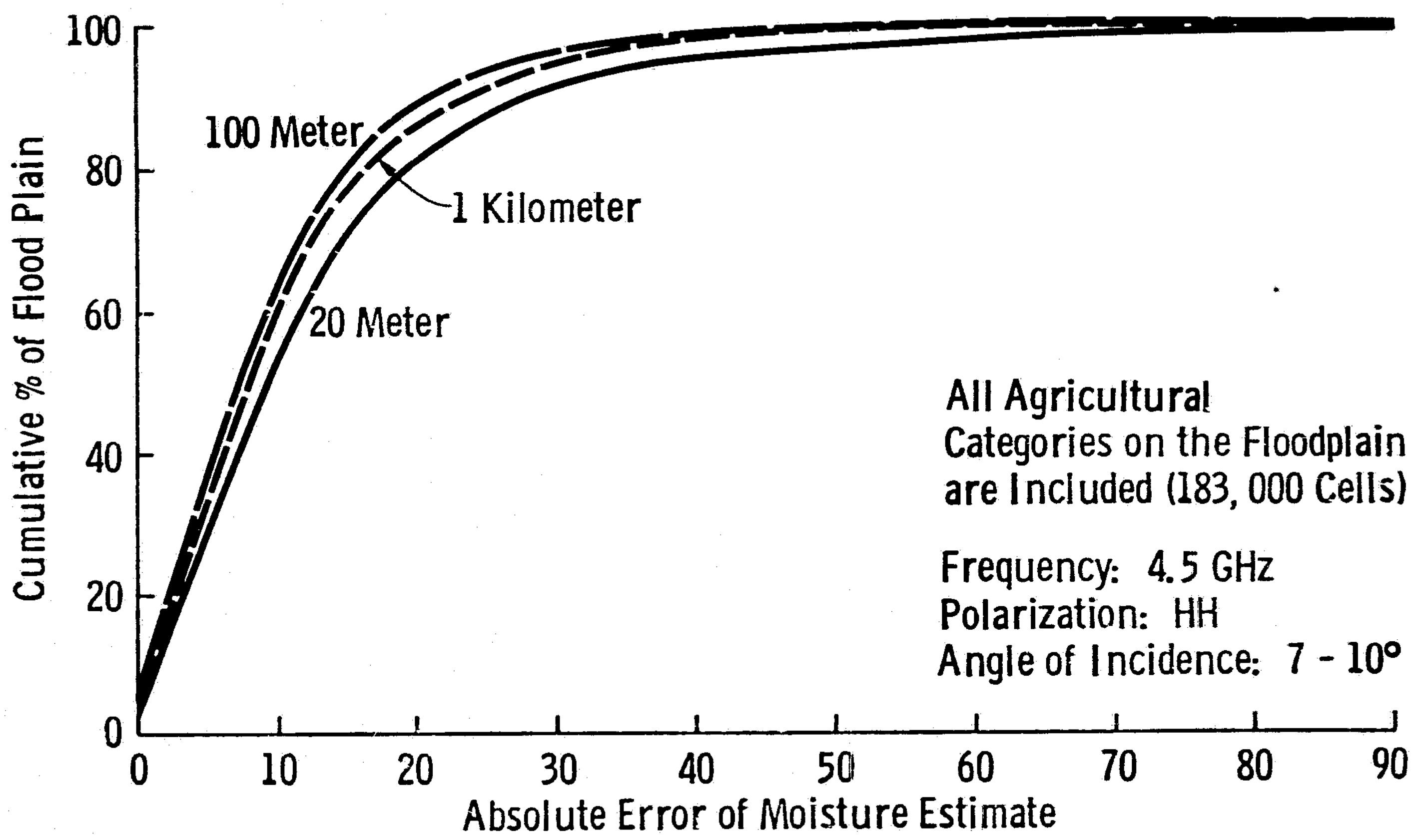

Figure III-9.- Accuracy of estimated percent of soil moisture 10 days after thunderstorm (after Ulaby et al., 1981).

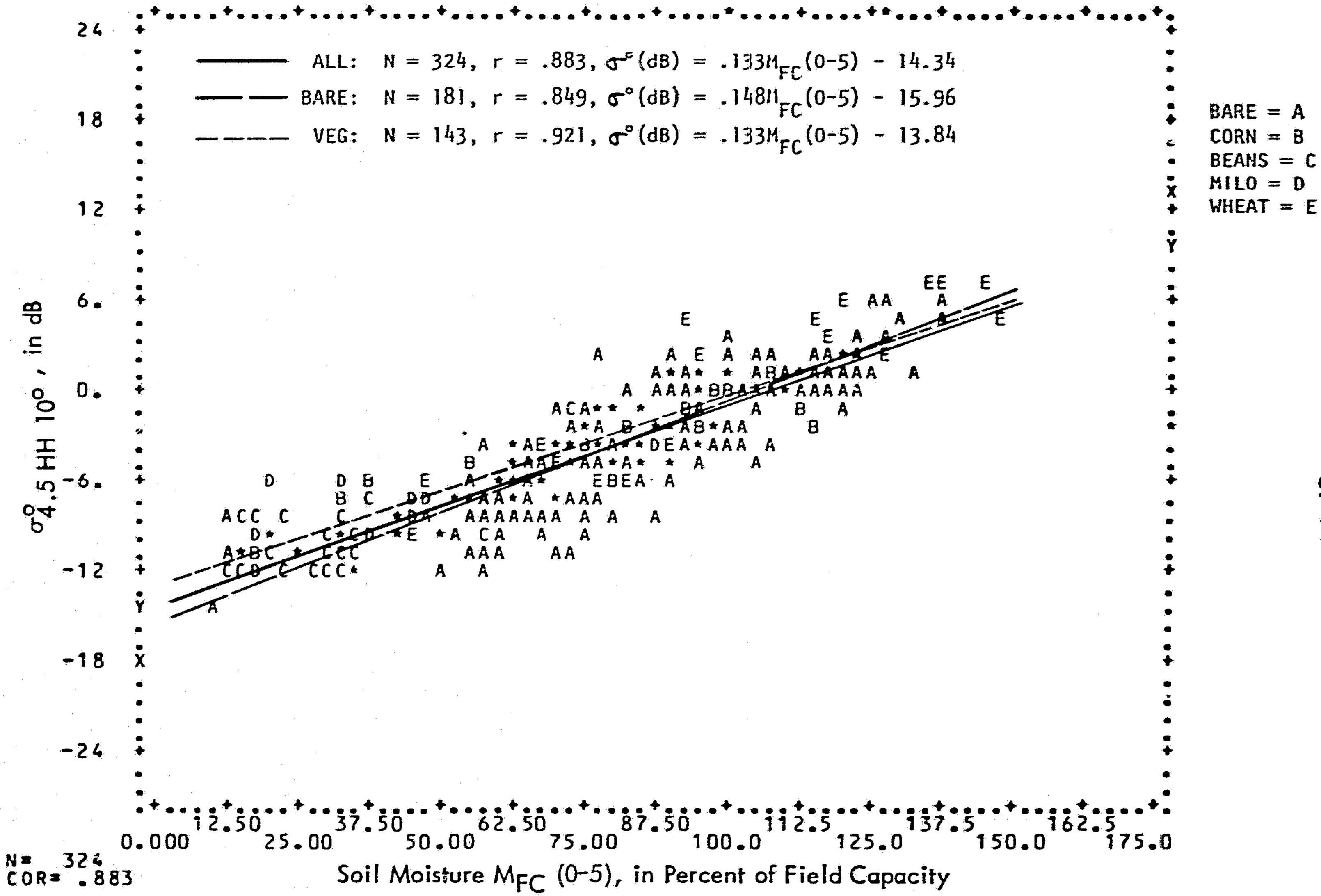

Figure III-10.- Radar backscatter response to soil moisture for bare fields and vegetation-covered fields.

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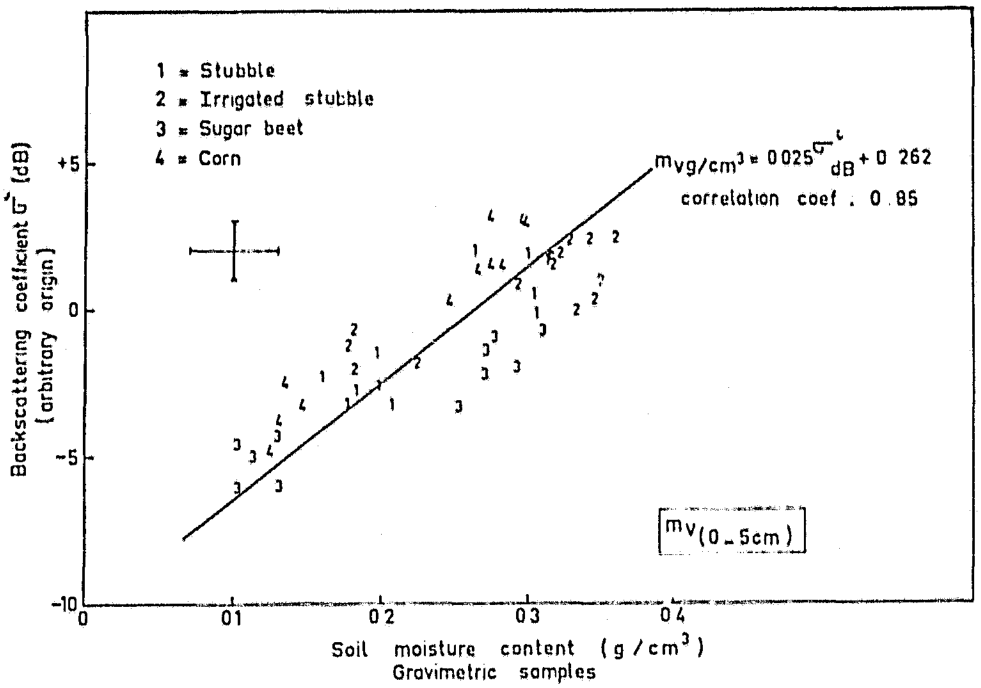

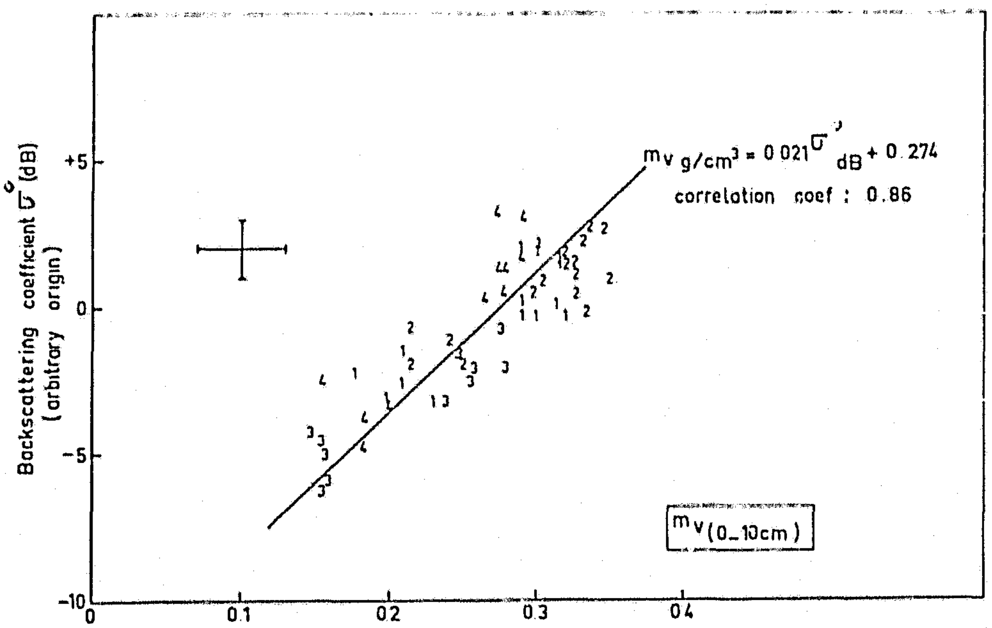

Figure III-11.- Radar backscatter as a function of soil moisture (vegetation) (after Bernard et al., 1981).

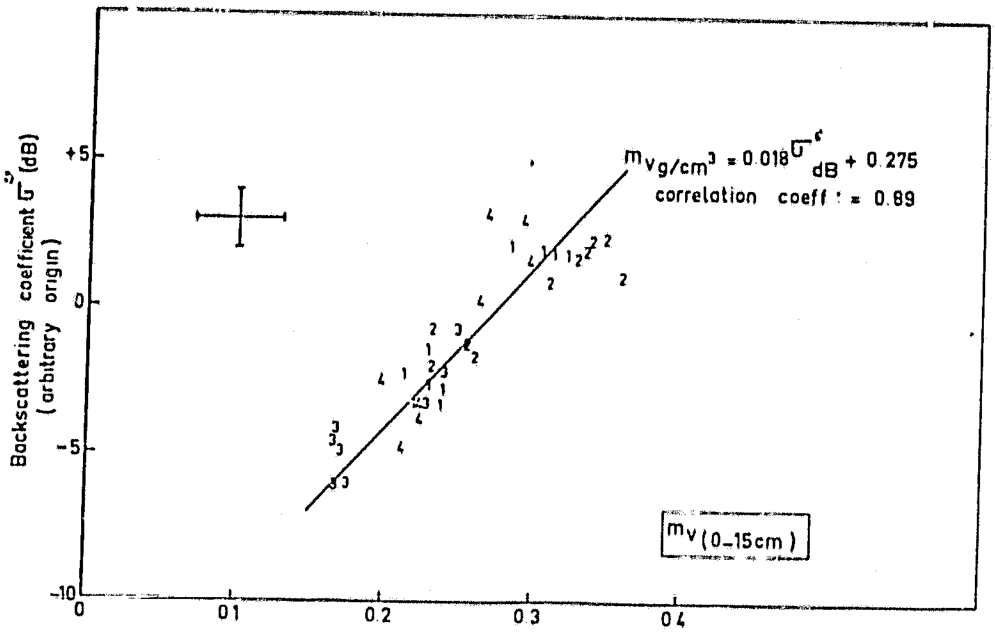

Figure III-11.- Concluded.

Planetary Environment in France (figures III-12 and III-13). If periodic patterns are present and if the row-depth to row spacing ratio is smaller than about 1/10, σ° is approximately insensitive to look direction for frequencies higher than 4 GHz, and therefore the configuration given above may be used, although some improvement in correlation to moisture may be obtained by operating with HV polarization instead. The above row-pattern characteristics are typical of conditions that prevail during most of the growing season in dry-land farming regions.

In regions where irrigation practices are common, row-depth-to-period ratios may be as high as 1/4, in which case the variation due to look direction becomes very large, thereby introducing ambiguities in the estimated value of soil moisture. In this case, HV polarization may be recommended because of its weaker sensitivity to look direction (in comparison to HH polarization). Ongoing studies of corn and soybean fields in the AgRISTARS Supporting Research Project show significant row direction effects (~9db) in non-irrigated fields. One possible solution to the row structure and orientation effects is to view the fields at azimuthal angles of 30 degrees or more from directly across rows. Since most fields are planted north-south or east-west, one could use a southeast or northeast look.

3. RESEARCH ISSUES

Relative to other applications, the utility of C-band radar for mapping soil moisture is much better understood because the bulk of the research conducted during the past several years has been at C-band. Further research is needed,

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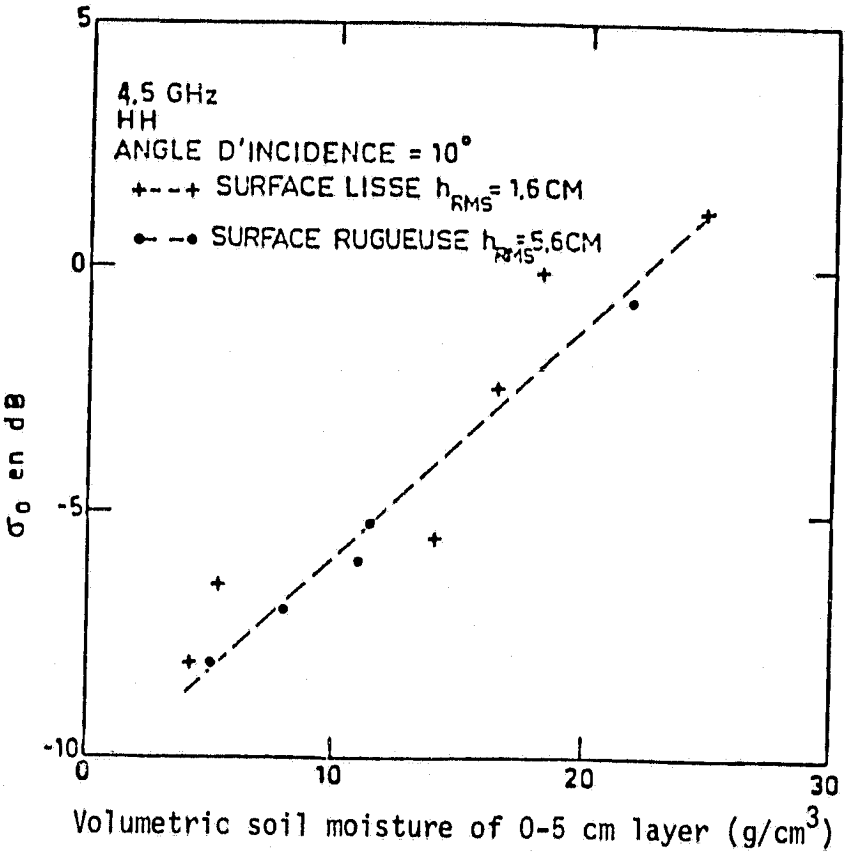

Figure III-12.- Variations of the backscattering coefficient $\sigma°$ with soil moisture constant for two soil surface roughnesses (after Le Toan et al., 1980).

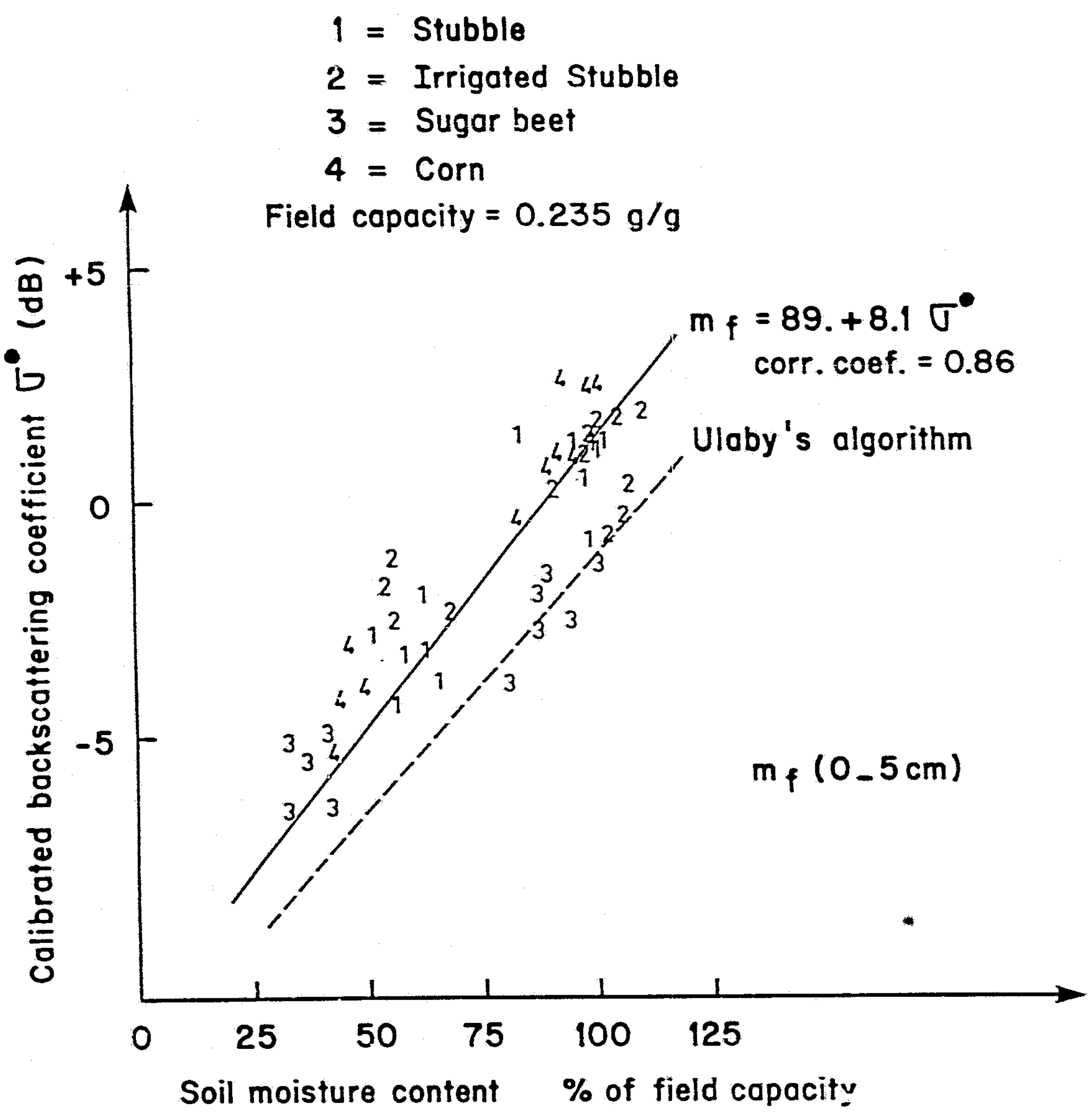

Figure III-13.- Comparison of radar response to that obtained by Ulaby (after Bernard et al., 1981).

however, to increase understanding of the improvement in soil moisture estimation accuracy resulting from the use of (a) HV polarization in addition to HH at C-band and (b) the use of L-band in addition to C-band. These questions are addressed in the proposed FIREX experiments outlined in Section V.

C. FORESTRY

1. APPLICATIONS NEEDS

The Resources Planning Act (RPAO) of 1974 mandates that the U.S. Forest Service determine the extent and condition of the forest and rangeland resources of the U.S. every 5 years. The Forest Service is currently developing techniques to meet this requirement using satellites (Landsat), aircraft, and ground-based data. The approach will involve multistage sampling to provide tabular information on a county-by-county basis, but will not require complete map information.

Different users have different information requirements. Private industry, State Department of Natural Resources, and National Forest Service personnel, for example, require maps showing the physical location and volume of the forest resources. This type of information is usually obtained at present on a periodic basis with aerial photography.

The U.S. Forest Service and others need to determine the location and extent of dying and dead timber in order to salvage this otherwise wasted timber, and also to remove a source of potential insect population growth. Forest fires destroy millions of dollars worth of resources every year. To aid in forest fire prevention efforts, the U.S. Forest Service maintains a fire danger rating system. The forest fuel condition, involving such parameters as the fuel amount and moisture condition is a key element in providing data input to the fire danger rating system.

Urban expansion and changes in the demand for agriculture land cause continuous change in the areal extent of the forest resource base. Both local and national predictions of timber productivity require effective monitoring of changes in the resource base on a cycle that is more frequent than the 10-18 year cycle currently achieved by the U.S. Forest Service. Private industry would like to be able to monitor changes on an annual basis and within a defined annual planning cycle. In some states, clear-cutting of forest areas must be monitored in a timely manner (perhaps monthly) for tax assessment purposes.

The overall aspects of the problem and the need to use SAR sensors to help and/or improve current practice may be summarized as follows:

a. Problem definition - measure forest biomass productivity. Investigate the use of SAR for identifying forest species, and assessing stand composition, stand density, stand vigor or condition, height/site quality and change by measuring spatial and temporal variabilities.

b. Present data collection methods and SAR potential. Aircraft photography and ground observations are currently being used. Manual methods are usually employed for photointerpretation and mensuration. Products are timber volume estimates and forest-type maps. SAR data offers the potential of digital data correlating to timber type, boundary delineations, biomass of standing vegetation, loss from stress, and site quality. SAR provides all-weather capability and additional information source for inclusion with Landsat/MSS and Thematic Mapper (TM) data.

c. Related SAR investigations. The ability of SAR measurement to provide difference in backscatter returns that are related to forest canopy density, arrangement, and vigor offers the potential to more effectively differentiate among various species and forest cover types than may be possible with MSS data, even from the TM. For example, the results of an analysis of the integration of Landsat MSS and Seasat L-band SAR data (Wu, 1981) indicate that while Landsat data can be used to delineate different forest types and allow for some species separation, the Seasat L-band SAR data provide additional information related to plant canopy configuration and vegetation density as associated with varying water regimes, and therefore allows for further subdivision in the classification of forested wetlands. Better classification accuracy was also demonstrated in swamp forests that are flooded with water.

Standing water beneath the forested wetland can be delineated because of high radar returns (Waite et al., 1981) and was the key factor for improving swamp forest classification. The pine forest with partial clear-cutting which causes shrubs and native grasses to be exposed among the tall pine crown clusters (Wu, 1980) can be accurately identified by Seasat L-band SAR data, but it causes spectral confusion of MSS data and misclassified it as marsh class. In addition, the use of cross polarization data in conjunction with linear polarization data provides improvement in delineating woodland from other crop vegetation in the mixed vegetation area (Ulaby et al., 1980).

A recent study was conducted over an area in France using the L-band JPL SAR system. For pine trees, the image intensity was found to be directly proportional to the height (Figure III-14) and age (Figure III-15) of the trees. The study was conducted by Riom and Le Toan of Paul Sabatier University (Toulouse, France).

2. MISSION REQUIREMENTS

Although the few experiments conducted to date show that imaging radar has the potential to provide useful information with regard to forest biomass productivity, no concrete information exists with regard to optimum angle of incidence, frequency or polarization. Moreover, the complexity of the forest environment precludes the possibility of determining answers to these questions within the FIREX study period (ending in September 1982). Hence, no specific mission requirements can be established at this time.

3. RESEARCH ISSUES

Research issues for forestry are very similar to those of agricultural crops. Due to the limited L- and C-band data acquired to date, the optimum angle of incidence, and the usefulness of dual frequency (L- and C-band) or dual polarization (C-like and C-cross) are not well determined by past studies. In addition, the special effects of topography (slope) on SAR returns in typical forest areas makes the assessments of mission configuration difficult without high quality SAR image data (as opposed to nonimaging radar scatterometer data). Since C-band and L-band SAR images cannot be acquired over U.S. sites in FY82 except at unacceptably high costs (with the CV580 SAR's), it appears that no new data sets can be acquired over U.S. forest sites in FY82. It is expected that such data will be acquired by the Canadians in Canada.

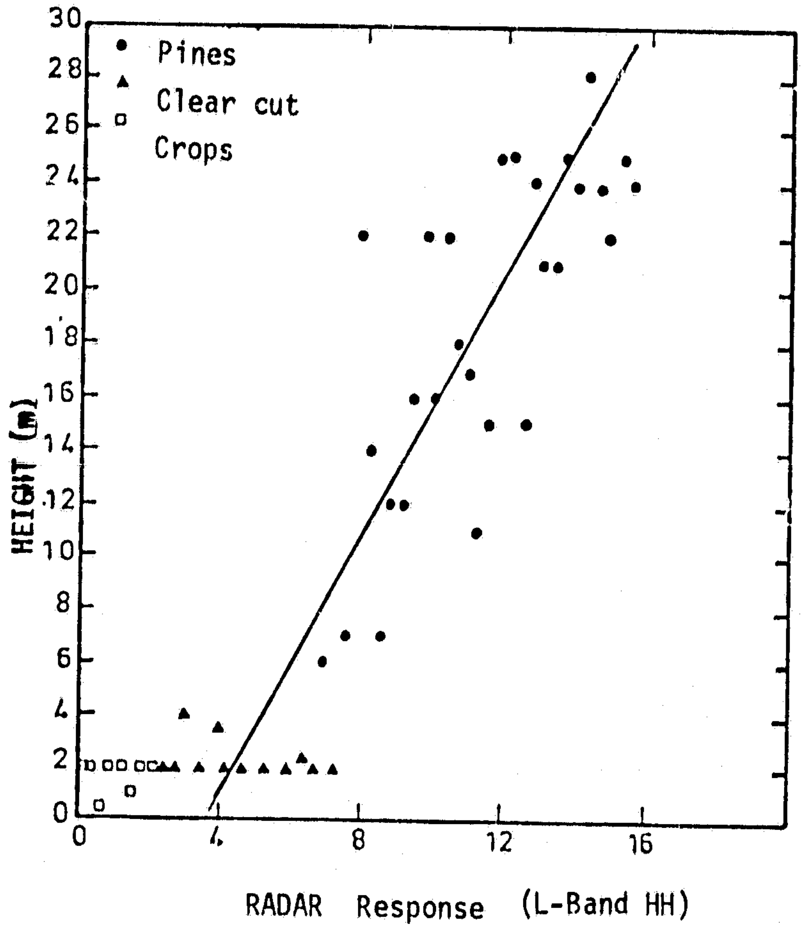

Figure III-14.- Relation between tree height and radar response (L-band HH) (after Riom and LeToan, 1980).

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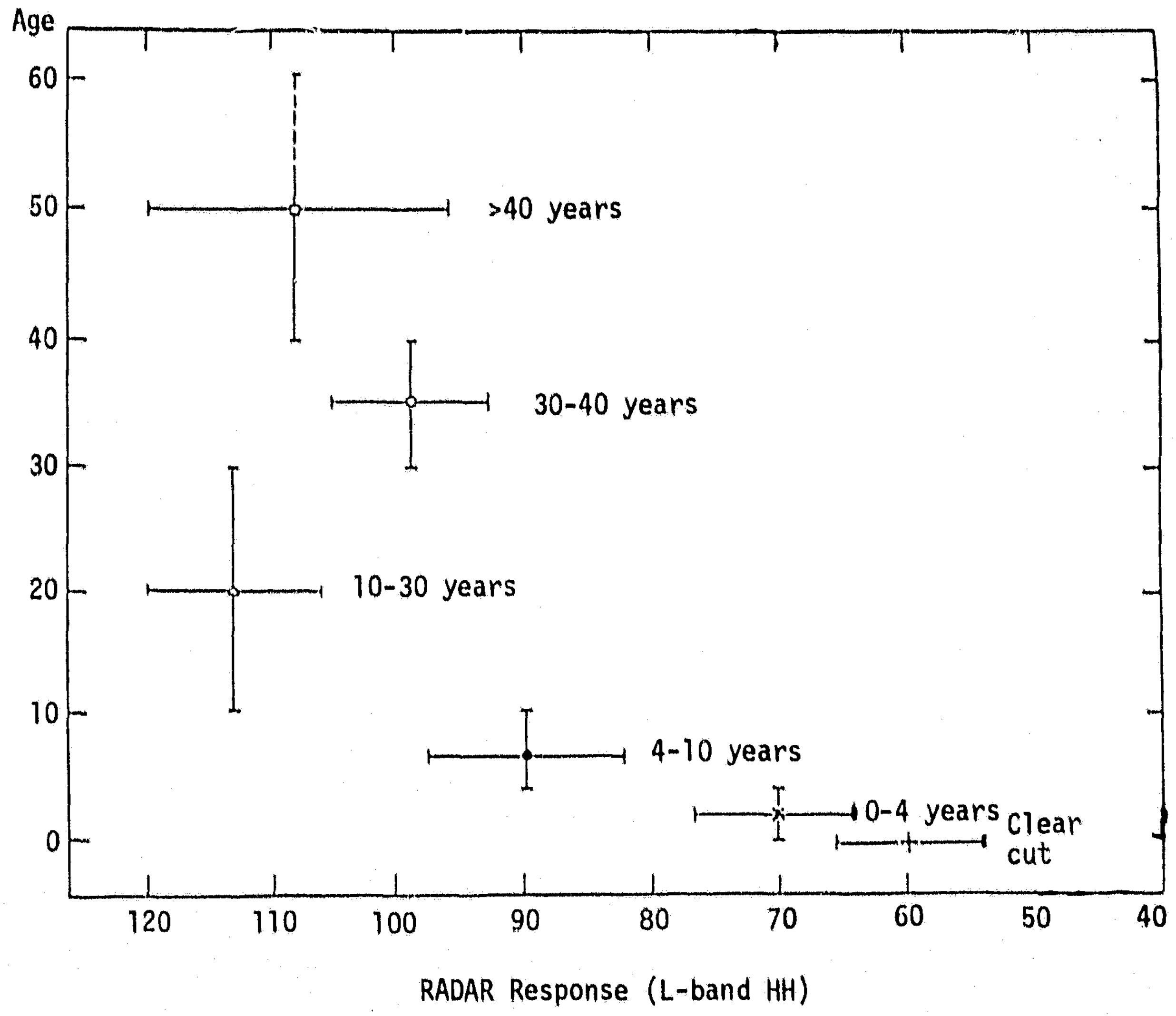

Figure III-15.- Effect of the age of pine stands on radar response (L-band HH) (after Riom and LeToan, 1980).

D. SNOW, WETLANDS, COASTAL LANDS, FLOODING, AND DRAINAGE

1. APPLICATIONS NEEDS

Measurement of snowcover extent, water equivalent and free water content of snow is very important for prediction of runoff and for determination of the amount of runoff expected. Soil state beneath the snow is also important for runoff predictions because permeability influences the quantity of snowmelt that will run off.

Snowcover mapping of mountain watersheds is currently accomplished through aerial and satellite imagery. Snowcover maps are combined with point samples of water content to estimate potential volumes of water available. Practical limitations (funding and manpower) severely limit the number of water content sampling locations. Thus, for large drainage basins, it is impossible to sample water content adequately. Moreover, in the Pacific Northwest and the Great Lakes areas, remote snow mapping is impeded by cloud cover.

Microwave radiation generally penetrates cloud cover and would permit regularly scheduled snow data collection without regard to weather or time of day. An International Working Seminar on Snow Studies by Satellites, sponsored by the World Meteorological Organization (October 1976), recommended that "... increased attention be given to research on the microwave remote sensing of snow with attention being given to theoretical studies, numerical modeling, and carefully-controlled field experiments." The seminar recommended further that "...a multispectral imaging microwave radiometer be included in a future satellite program" (World Meteorological Organization, 1976).

The general discipline of land cover/land use involves mapping of the various categories of land cover including natural vegetation. Wetlands and coastal zone management are parts of land cover management program. Since these areas are often highly variable and involve dynamic processes such as storm or hurricane impact, the frequent coverage and large area synoptic view provided by remote sensors can be most valuable.

The desired capabilities of remote sensing systems for wetlands and coastal zone management include vegetation mapping, detection of surface and standing water, and shoreline change detection.

Wetlands vegetation identification and mapping require the delineation of basic vegetation type and species level data: marsh, shrub, and forest. Surface texture data could provide additional information related to height and density of vegetation as associated with varying water regimes and, therefore, enhance the accuracy of delineating forested wetlands and harvestable timberlands of the coastal flatlands.

Accurate delineation of coastal wetlands boundaries hinges on the ability of radar to penetrate vegetative cover (swamp, forest, marsh, and floating aquatic plants) and then indicate whether the underlying surface is land or water. Both surface and standing water identification are significant in estimating estuarine marsh productivity.

The natural estuarine habitat is many times more food productive than farmland of equal area. Most food from the sea and the finfish and shellfish such as oyster, shrimp, and crabs which are the main products of coastal fisheries industry are directly or indirectly dependent on estuarine basic productivity, which in turn is a function of the amount of available marsh vegetation.

Existing techniques of marsh productivity estimation provide for delineation of different species of marsh grasses, but fail to detect the inundating standing water beneath the marsh grasses. The inundating water boundary is a significant parameter that affects marsh productivity and the transport of nutrient from marsh to the surrounding water bodies (Butera et al., 1981). SAR data which had demonstrated the capability of detecting standing water beneath the swamp forest may provide the boundary of wet and dry marsh and thereby lead to a more accurate estimation of the productivity of marsh grasses.

Remote sensing has been invaluable in observing short- and long-term shoreline changes. Aerial photography using a mapping camera, with its high resolution and cartographic accuracy is ideal for observing local changes. Larger area changes can be quite effectively monitored with Landsat MSS data and the effectiveness is likely to increase when the higher resolution Thematic Mapper data become available. A radar system could be useful for monitoring long-term shoreline changes in environments frequently shrouded by cloud cover. Radical, rapid changes in shoreline features often occur during storms, that is, during cloudy periods. The high temporal and spatial variability of the coastal processes would be more efficiently observed from an aircraft system with high spatial resolution and frequent coverage.

Flood damage estimates are needed for water management and control purposes so that land use plans can be intelligently devised. Updating land use information can be accomplished through utilization of satellite-acquired data especially for large geographic regions (NRC, 1980). The ability to map extent of inundation enables establishment of flood hazard zones along streams (Rango and Salomonson, 1974).

Synthetic Aperture Radar data are useful for determining the location and extent of flooding. Since water acts as a specular reflector to the radar signal, discrimination between land and water is easily accomplished with the SAR. Water appears smooth and dark (low radar returns) whereas the surrounding land is brighter and rougher (higher radar returns); thus, the C-band SAR should be excellent for the purpose of flood extent mapping.

Mapping surface water (wetlands, ponds, lakes, reservoirs, rivers, flooding, etc.) is important in the general framework of water resource management. In the absence of vegetation, the discrimination between water and land surfaces by passive microwave sensors is made on the basis of the large difference in emissivity between water and land at all microwave frequencies. Longer wavelengths are particularly appealing because of their superior vegetation penetration capabilities and because the difference in emissivity between water and land surfaces increases with wavelength. Radar can also map water bodies; in most all cases, water is observed to produce a much lower return (tone) on radar imagery.

The ability of active microwave sensors to map flood inundated areas under cloudy conditions is extremely important since such a capability can be used for conducting relief efforts, assessing loss of life and property and delineating the extent of the flood plain. Mapping flooded land with radar imagery is illustrated in Figure III-16. The image was acquired through a cloud cover while flooding was in progress. On the radar image the rivers and the flooded areas appear black, corresponding to a weak backscatter return.

Observations of basin shape, stream network characteristics, land use and drainage density permit one to infer the general characteristics of the water yield - such as the location of ground water and the magnitude of the mean runoff (Salomonson and Rango, 1974). Landsat data have been used successfully to delineate and monitor hydrological features, and radar data have proven to be excellent for this purpose as well. Radar imagery is particularly well-suited for areas that are frequently shrouded by cloud cover. The better resolution afforded by radar imagery allows one to detect and map smaller tributaries than is possible with the Landsat/MSS imagery. And the ability of SAR data to show the relief of the river banks allows one to detect the tributaries quite easily even if water is not in the channels year-round.

Expected benefits of utilizing SAR data for flooding studies include (Deutch and Ruggles, 1974):

1. disaster relief agencies will get an overview of early damage estimates;
2. regional planners will be able to assess the best use of floodplains;
3. housing authorities will be able to determine areas subject to flooding;
4. engineers will be able to evaluate effectiveness of flood control structures.

RADAR FLOOD MONITORING

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Figure III-16.- Radar image of the 1973 Missouri River Flood near St. Louis. Images made at night through some cloud cover.

2. MISSION REQUIREMENTS

Quantitative studies of the radar backscattering behavior of snowpacks have, so far, been limited to measurements from truck-mounted platforms, with the major emphasis being at frequencies above 8 GHz. Results from these studies (Ulaby and Stiles, 1980; Stiles and Ulaby, 1980) indicate that the radar backscattering coefficient, $\sigma°$, is strongly dependent upon snowpack water equivalent (Figure III-17) and snow wetness. The dynamic range of $\sigma°$ due to water equivalent increases from 5 dB at 16.6 GHz to 9 dB at 9 GHz. Assuming this trend continues, the dynamic range at 5 GHz should be in the neighborhood of 12 dB, although the effects of the moisture content of the underlying soil may penetrate through the snow cover.

Dry snow and ice exhibit low loss characteristics in the microwave region, thus permitting considerable penetration at the longer wavelengths (≥ 6 cm). Measurements of the scattering coefficient of soil in the 4-30 cm wavelength range with and without a 15 cm layer of dry fresh snow cover indicated no measurable change due to the presence of the snow (Ulaby et al., 1977). For wet snow, $\sigma°$ indicated a strong sensitivity to snow water equivalent (Figure III-18) although it was suspected that $\sigma°$ was actually responding to the snow liquid water content in the snowpack. Figure III-19 shows that a 4.6 GHz, the magnitude of the change in $\sigma°$ increases linearly with increasing snow liquid water content. Corresponding to a change of 4.5% in liquid water content, $\sigma°$ changes by about 7 dB.

Additional experimental observations were conducted in 1980 by the University of Kansas at several sites in Colorado. The data are being analyzed and a

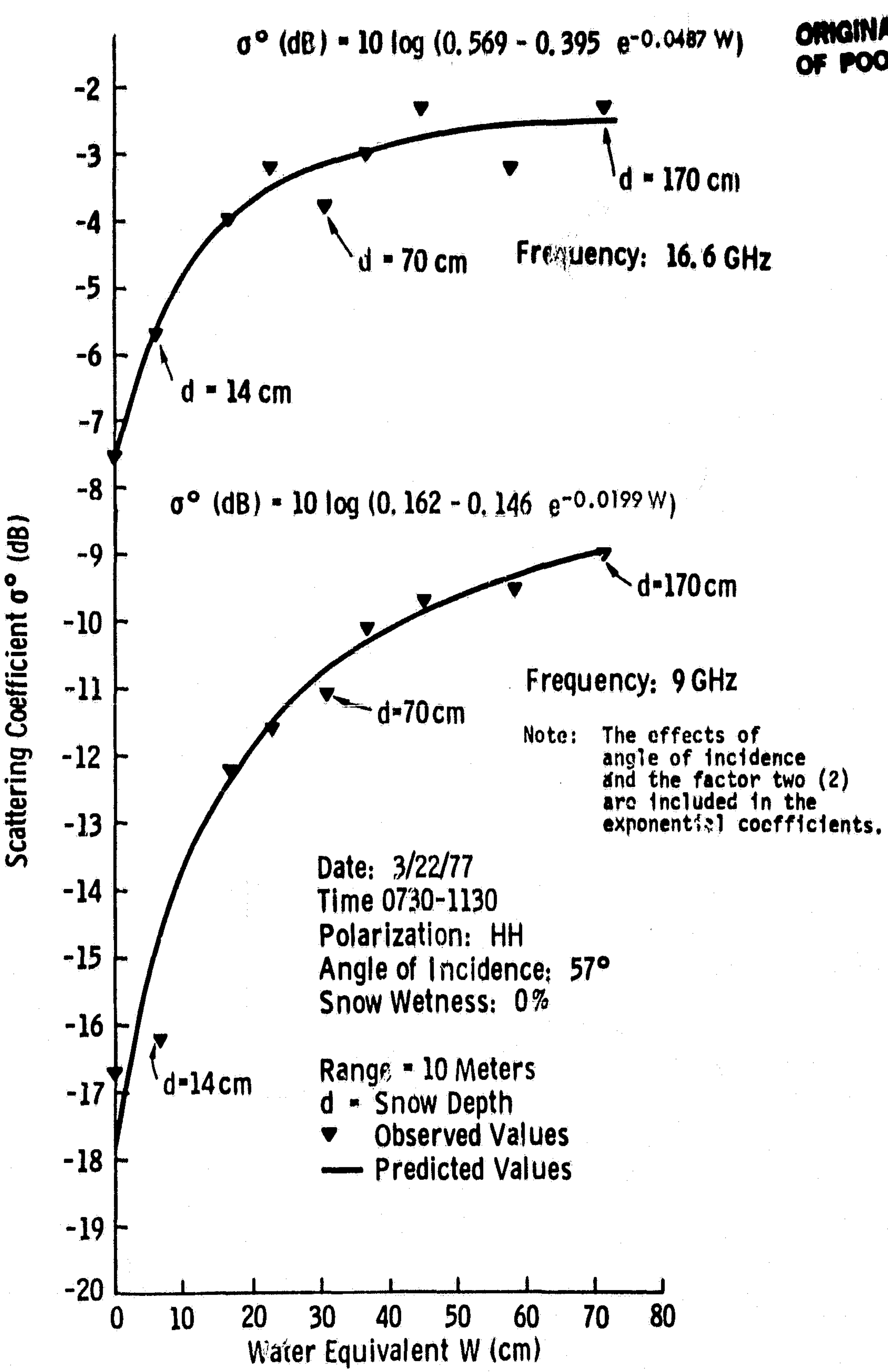

Figure III-17.- Scattering coefficient response to snow water equivalent (after Ulaby and Stiles, 1980).

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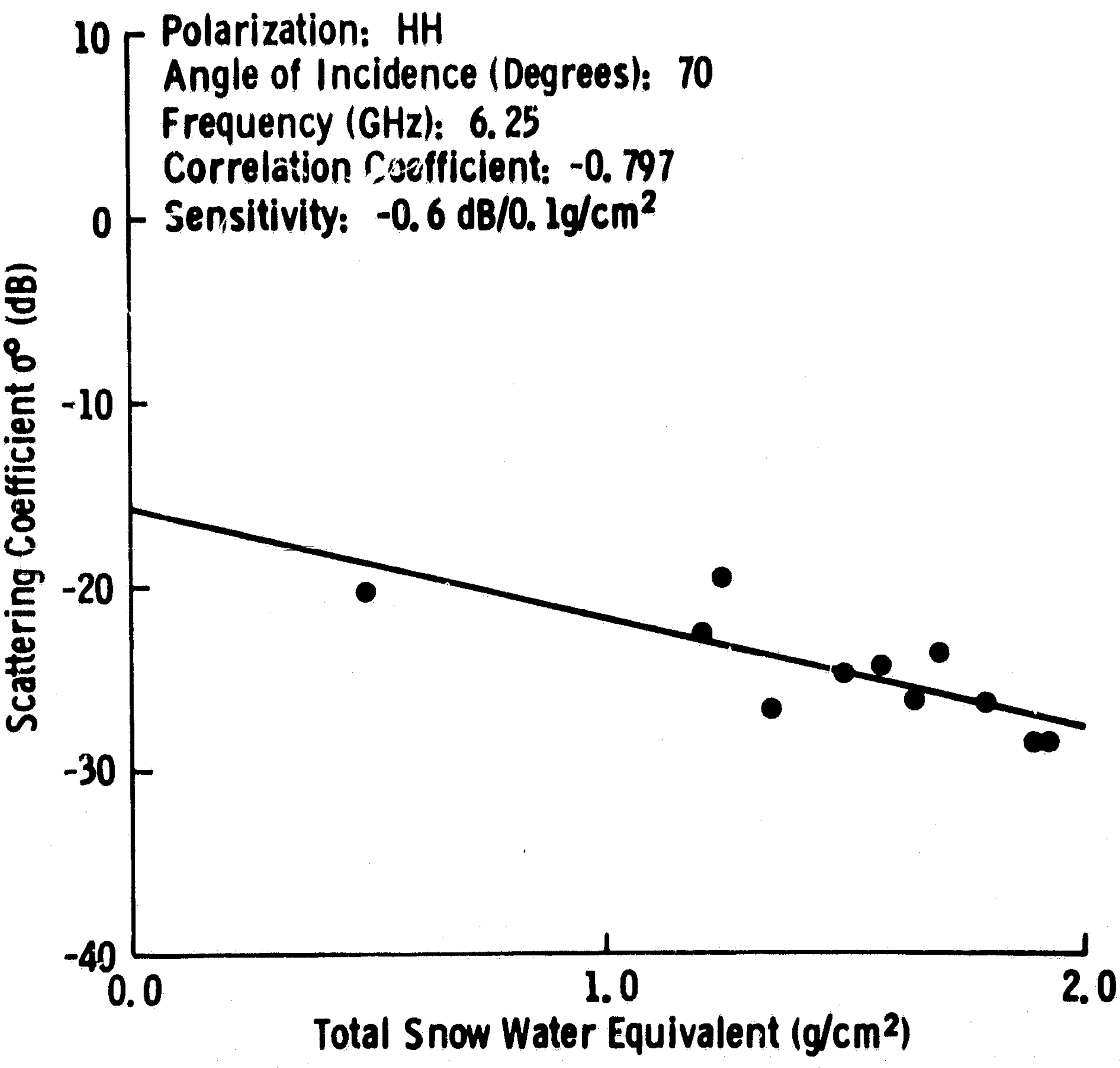

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Figure III-18.- Response of σ° to Total Snow Water Content per Unit Area.

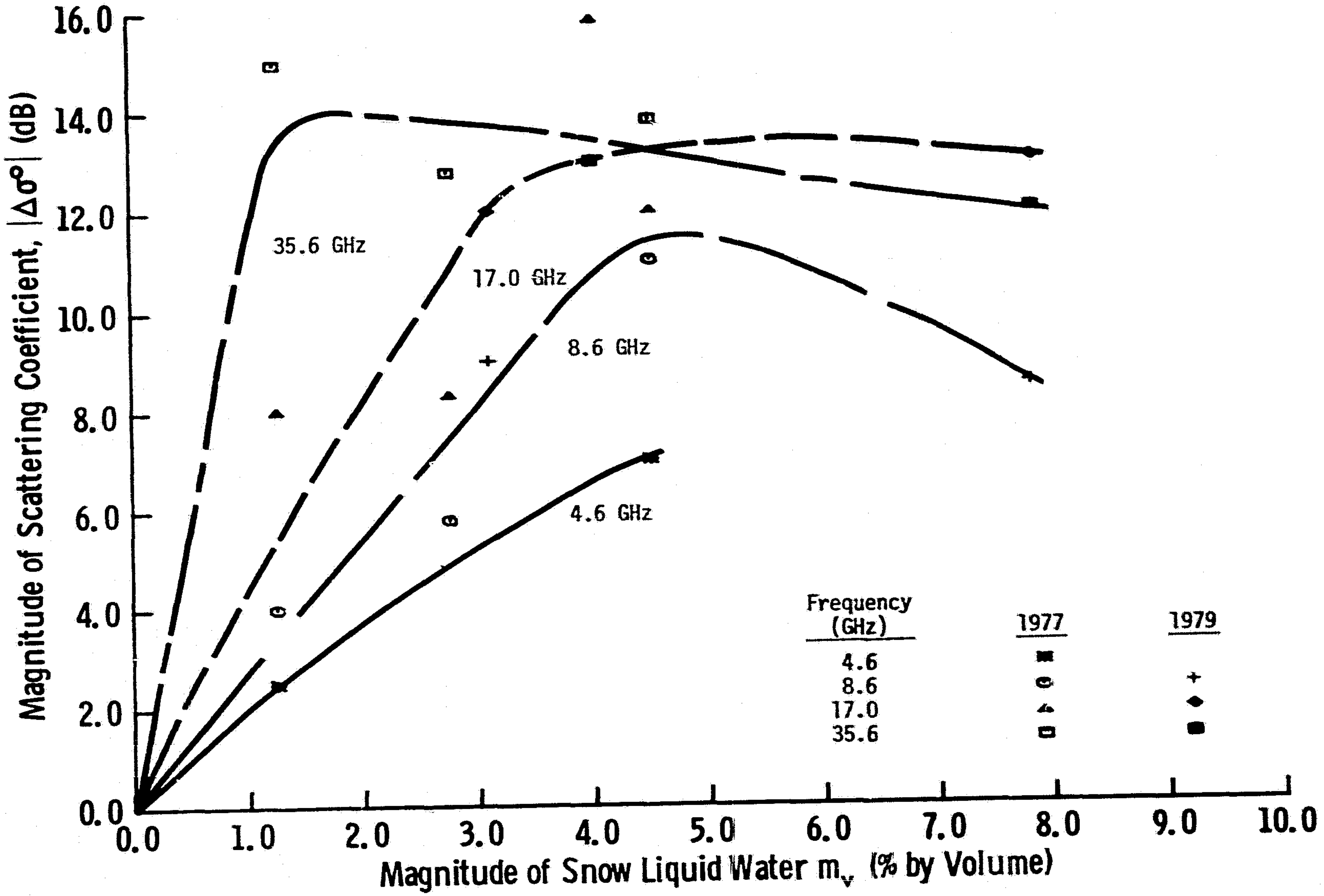

Figure III-19.- Dependence of σ° on snow equivalent water content at several frequencies (after Stiles et al., 1981) report outlining the results is expected by the end of 1981. The current status, however, indicates that a C-band radar is potentially useful for determining the snow water equivalent, snow wetness, and the state of the ground beneath the snow. The key to separating these quantities is multi-date coverage with nighttime and daytime passes. A 25-100 m resolution imaging radar mounted on a polar orbiting satellite would be useful for coverage of western U.S. snowpacks. This would allow measurements of the snowpack in forest clearings and numerous points across a watershed for translation to large area water equivalent and liquid water content (NASA, 1978). Measurements of snow water equivalent are conventionally obtained at only a few points in a basin which may or may not be representative of that basin. Area-wide measurements are needed for optimal results.

Before the exact snow-oriented performance capabilities of a C-band radar can be specified, experiments need to be conducted to determine the following:

1. Dielectric properties of snow
2. Effects of crystal size on $\sigma°$
3. The response of $\sigma°$ to snow water equivalent under varying natural conditions
4. The effects of surface roughness on $\sigma°$
5. Quantification of attenuation and penetration depths for different wetness conditions and crystal sizes
6. Effect of the state (frozen versus unfrozen) of the ground beneath the snow, on $\sigma°$

3. RESEARCH ISSUES

The same research issues arise for wetlands, coastal lands, flooding, and drainage applications as where defined for agriculture and forestry. Again, due to the spatial nature of the information content in SAR data for these applications, and due to the non-availability of U.S. SAR data in FY82, these research issues cannot be addressed.

IV. EXPERIMENTAL RESEARCH PROGRAM PLAN

SECTION SUMMARY

- This section describes a set of possible experiments that would address the research issues defined in Section III.

- Agricultural Experiments
  - Melfort, Saskatchewan (small grains; CV580; KU MAS: address issues of use of dual polarization or dual frequency for crop identification and canopy condition assessment)
  - Webster County, Iowa (corn and soybeans; NASA C130B Scatterometers; same issues as above plus issue of optimum incidence angle)
  - Cass County, N. Dak. (small grains; same sensors and issues as for Webster site above)
  - Eudora, Kansas (wheat, corn, soybeans; retrospective analyses of 1975-77 MAS data; same issues as for Webster site above)
  - Colby, Kansas (1978 data set)

- Soil Moisture Experiments
  - Webster County, Iowa (MAS 1-8; C130B Scatterometers; addresses issue of revisit interval and the exact choice of frequency (5.3 GHz versus 4-5 GHz) and incidence angle on the 10-20° range)

- Forestry Experiments
  - Kershaw County, S. Carolina (L- and C-band SAR data needed -- but not yet available; addresses issue of optimum viewing angles and use of L- and/or C-band (like and/or cross) for forestry)
  - Clearwater National Park, Idaho (same as for Kershaw County site)

- Snow, Wetlands, Coastal Lands, Flooding, and Drainage Experiments
  - Minot, N. Dak. (snow site; L- and C-band SAR's)
  - Pearl River Basin, Miss. (wetlands, coastal lands, flooding, and drainage site)

IV. EXPERIMENTAL RESEARCH PROGRAM PLAN

The following experimental research program plan is designed to produce specific data sets which will help narrow the choice of SAR parameters to support the high priority crop identification/condition and soil moisture applications identified in Section III. Recognizing the very limited funding available to support such an effort, the Study Team decided to concentrate its resources on the top two applications areas, i.e., crop identification and condition and soil moisture mapping, while recommending that funding from other sources (including Canadian) be used to support important, but secondary experiments to decide optimum SAR parameters for forestry, snow cover, drainage mapping, etc. The program is designed with the assumption that investigations complementary to FIREX and already planned for FY82 (e.g., AgRISTARS) will take place.

This experimental program plan is seen as an integrated effort, in which <u>all</u> of the recommended crop identification and condition and soil moisture investigations should be carried out, if a meaningful data set is to be obtained which can be used to recommend the best SAR parameters. The estimated cost of this experimental program in $220K. If funding at or near this level is not available, it is recommended that no such experimental program be conducted at all, since the potential information return of a fractional program does not justify the effort required.

The recommended plan is divided into two levels of applications priorities.

<u>Primary Applications</u>

A. Agriculture (crop identification and condition)

B. Soil Moisture (mapping)

Secondary Applications

C. Forestry Mapping

D. Snow Cover, Wetlands/Coastal, Drainage Mapping

The overall objective of the plan is to determine by an experimental program the best choice of frequency (either L-band or C-band), angle of incidence and polarization for a spaceborne imaging radar when used together with visible and infrared imagery. Included within this objective is the determination of the improvement in classification or mapping accuracy afforded by using more than one SAR parameter, e.g., two frequencies (L-band plus C-band at a single polarization and single angle of incidence), or two angles (at a single polarization and single frequency), or two polarizations (at a single angle and single frequency).

This experimental program then has a much more specific focus than any previous investigation, in that it seeks to determine (a) what is the best L-band/C-band SAR combination, and (b) the potential quantitative information available from such a spaceborne system. The program seeks to make maximum use of other on-going experimental investigations such as (a) planned AgRISTARS investigations at Webster County, Iowa, and Eudora, Kansas, sites, and (b) planned CCRS RADARSAT investigations at the Melfort site in Province of Saskatchewan.

A. AGRICULTURE

1. OBJECTIVE

The overall objective of the FIREX Renewable Resources Experimental Program for agriculture is (1) to determine the best choice of incidence angle (within the range of 45-60°) at C-band for agricultural crop identification and canopy condition assessment and (2) to determine the degree to which crop identification and canopy condition assessment are improved by the addition of L-band data to a C-band configuration and/or the addition of crop polarization data (at C-band) to the baseline like polarization configuration.

These two objectives address the specific research issues defined in Sections II and III above. The tradeoffs involved are the effects of incidence angle change on backscattering and measurement precision and the improvements offered by adding frequencies and polarizations versus the increased costs of the same.

2. SCOPE

The proposed research is limited to that research that can be carried out and completed by the end of FY82. Thus, the use of existing or already planned new data sets and sites is emphasized. Crops of interest shall be limited to corn, spring and winter wheat, soybeans, spring barley, and sunflowers since ground-based and aircraft-based radar systems have been used to acquire data for these crops in the past and in on-going NASA programs. In FY82, repeated use of the C-130B scatterometers is necessary in the U.S. sites since the C-band SAR on the RB57 will be taken out of service to allow reconfiguration for the NASA CV990 aircraft, and the cost of acquisition of CV-580 SAR data over U.S. test sites is prohibitively high.

Specifically, the following sites are recommended:

a. Melfort, Saskatchewan (small grains identification and condition)
b. Webster County, Iowa (AgRISTARS supersite for corn and soybeans identification and condition)

c. Eudora, Kansas (small grains, corn, soybeans, and sorghum identification and condition; also soil moisture mapping).

In addition, it is recommended that the research include analysis (heretofore not performed) of C-band truck spectrometer data from crops taken from 1975-77 using the University of Kansas MAS 1-8 system.

3. APPROACH

To satisfy the specific objectives above, data sets that have been acquired in past experiments and new FY82 data sets would be analyzed to determine the information content of a C-band like polarization dual-angle system (15 and 45 degrees from nadir) for agricultural applications versus a C-band like polarization 60° (and 15°) system, a dual frequency (C-band and L-band), or a dual polarization (like and cross) single frequency system. Assessments of information content will be based upon multidate data sets as opposed to single date data. The improved performance of these alternate systems as compared to the baseline system will be based upon the results of classification procedures used with Landsat/MSS and TM multidate data image such as clustering, maximum likelihood classification, and profile model classification. The data set acquired in the past of specific interest are the Colby ASME data acquired in 1978, the Cass County, North Dakota, data acquired in 1980 and 1981, the Webster County data acquired in 1980, and the ground-based data acquired near Lawrence, Kansas, in 1976-1981. These data sets are described in appendix A. Criteria for performance will include crop type classification accuracies including commission and omission error matrices and crop canopy characteristics parameters (such as canopy water content, crop stage of development, leaf area index, biomass, and canopy morphological description parameters) estimation accuracies. These performance criteria will be compared to similar criteria based upon Landsat/MSS data both as separate and joint data (MSS plus radar) with full recognition of the adverse effects of clouds on Landsat sensor data.

To illustrate the similarities and differences between MSS and radar multidate data, consider figure IV-1. The green vegetation index or greenness as derived from MSS data in Iowa in 1978 is plotted versus day of year. The dashed line represents a hypothesized continuous distribution between measured points from Badhwar's profile model. On the same plot, the multidate distribution of radar backscatter at 17 GHz VV 50° is shown for data acquired by the University of Kansas in a truck experiment in 1975. The display of these two disparate data sets on the same plot, although technically inappropriate, is to illustrate a point. Note that greenness rises sharply on Day 150, goes through a single peak on Day 211, and falls back to its original level (soil background) by harvest on Day 282. The radar data also show a rapid increase in early season, goes through a general peak, and falls to a low level by harvest. It is true also that the radar data show more variations around this trend than do the MSS data. Note, however, that many potential Landsat/MSS acquisitions were not made (as shown by the question marks) due to cloud cover. In 1978, the site was viewed every 9 days by either Landsat 2 or 3. According to research conducted by Ulaby, the variations in radar backscattering of corn canopies for this radar configuration is due to variations in the density of water in the canopy. The overall increase and decrease in σ° with calendar date is due to the growth and senescence of corn with time. Thus, it appears that radar offers similar information (i.e., time series profile of canopy growth) to that

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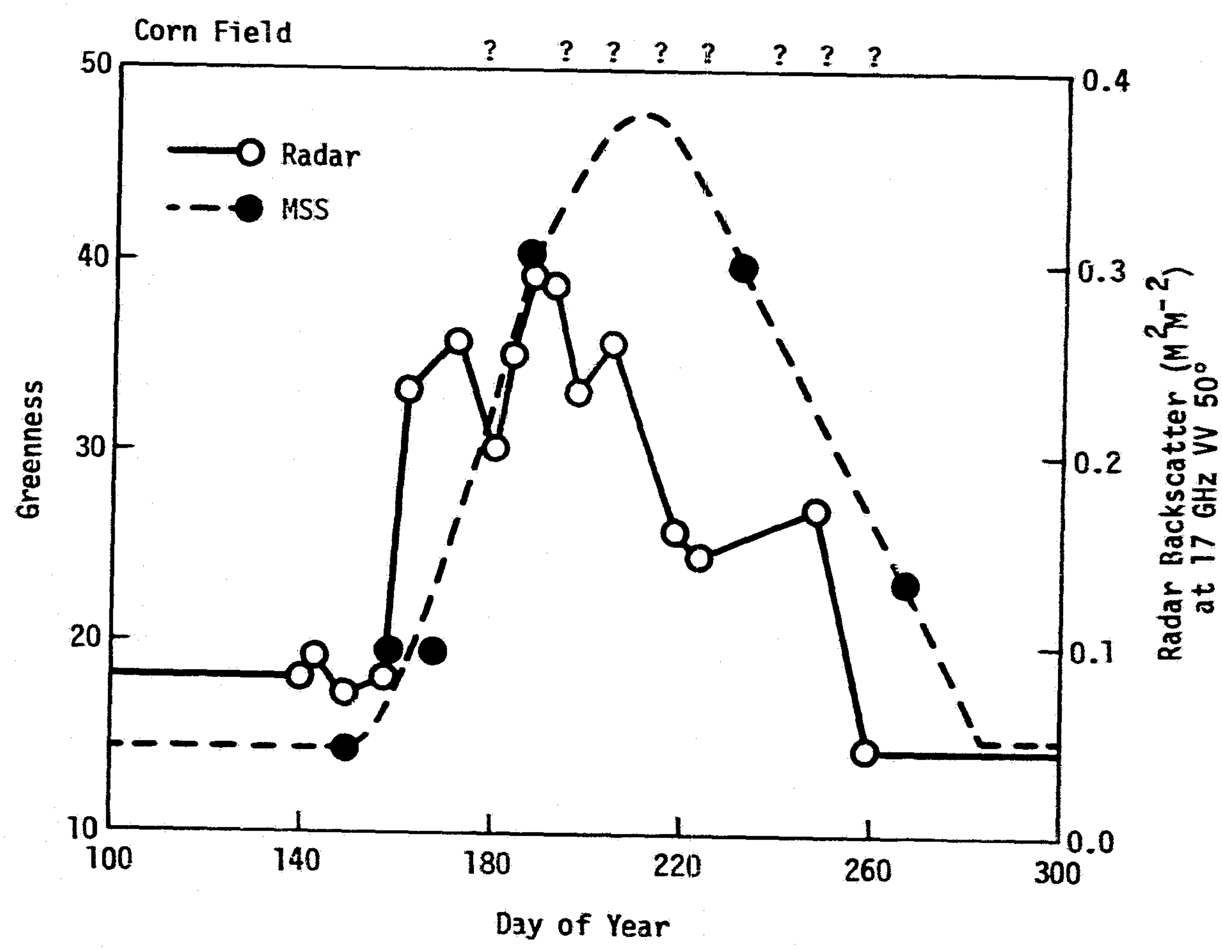

Figure IV-1.- Comparison of MSS and radar information for corn.

of the MSS, but different in that MSS responds mostly to LAI changes while radar responds mostly to wet biomass changes. It is important to note that the above remarks have not been proved but are a working hypothesis. The truth will be determined in the satellite-based experimental program.

In addition to the retrospective analyses of previously acquired data, a new data set shall be acquired in FY82 specifically for the purpose of meeting the objectives of the FIREX study above. Both ground-based and aircraft-based experiments will be carried out in FY82 over the Webster County, Iowa, site and Cass County, North Dakota, site (aircraft only) used in previous year's experiments in addition to the Melfort site in Saskatchewan. The quantity and quality of supporting ground truth measurements at Webster County in the aircraft-based experiments will be increased for the FY82 experiments compared to the FY80-81 experiments to allow for the addition of the investigation of the utility of L- and C-band system configurations for crop canopy condition assessments.

4. CV-580 SAR DATA REQUIREMENTS

It is the understanding of the U.S. Renewable Resources Study Team that the CV-580 SAR will be committed in FY82 to a multidate agricultural experiment at the Melfort site in Saskatchewan Province, Canada. It is the desire of the U.S. team to cooperate in this planned experiment for the CV-580 in FY82 by providing the University of Kansas C-band truck spectrometer (MARS--Mobile Agricultural

Radar Scatterometer) as a ground-based instrument, and the associated KU support team. This would allow the comparison of measured backscattering coefficients over wheat fields by the KU scatterometer to a radar image of similar angles and polarizations. Calibration of the CV-580 SAR images could be made through this procedure. It is recommended that data sets using the CV-580 C-band SAR and the KU C-band truck spectrometer be acquired every 10 days through a 6-week period in mid season.

In the course of the current study, it has been learned that there is an agreement between the Canadian Centre for Remote Sensing (CCRS) and the Environmental Research Institute of Michigan (ERIM) wherein all SAR data flights over U.S. territory of the CV-580 system must be contractually handled through ERIM. At a verbally quoted average ERIM price of $4K per flight hour (including ferry time), the cost to the NASA FIREX activity quickly becomes prohibitive for acquiring L-band and C-band SAR imagery at the necessary 10-day intervals required for crop identification experiments over U.S. test sites. As a consequence, there are no CV-580 SAR data flights requested over U.S. test sites.

5. SUPPORTING DATA REQUIRED

The nature of the existing and planned (for AgRISTARS) ground truth and aircraft or spacecraft visible and infrared data has been discussed in detail in appendix A for the Webster County site. These should continue as planned. In addition, however, the FIREX Renewable Resources Study Team needs the following data for agriculture:

a. Quantitative soil moisture and bulk density measurements - (0-5 cm depth) at 10 locations in each field spaced evenly within 2 hours of aircraft overflight times. Oven drying methods should be used.

b. Quantitative canopy moisture content measurements at 10 locations in each field spaced evenly within 2 hours of aircraft overflight times.

c. Soil roughness parameterization on the day of each overflight for each field.

d. Row height and general structural shape for each field on the day of each overflight.

e. Canopy closeup photographs for each field on the day of each overflight for canopy morphology determinations.

f. Leaf area index (LAI) estimates for each field on the day of each overflight. A possible cost effective technique would be to use visible-infrared aircraft data to estimate LAI's.

6. SITE LOCATIONS AND DESCRIPTIONS

a. Melfort Site, Saskatchewan

This is a former LACIE site and is planted predominantly with wheat. It would be used for wheat identification and condition, as described in a subsequent chapter. Confusion crops are barley and sunflowers. See figure IV-2 for a site map.

b. Webster County Site

The Webster County site is located in a corn and soybeans crop area in west central Iowa near 42°23.00' north and 94°10.00' west. A site map is shown in figure IV-3. It is a north-south, east-west rectangular shaped area that is

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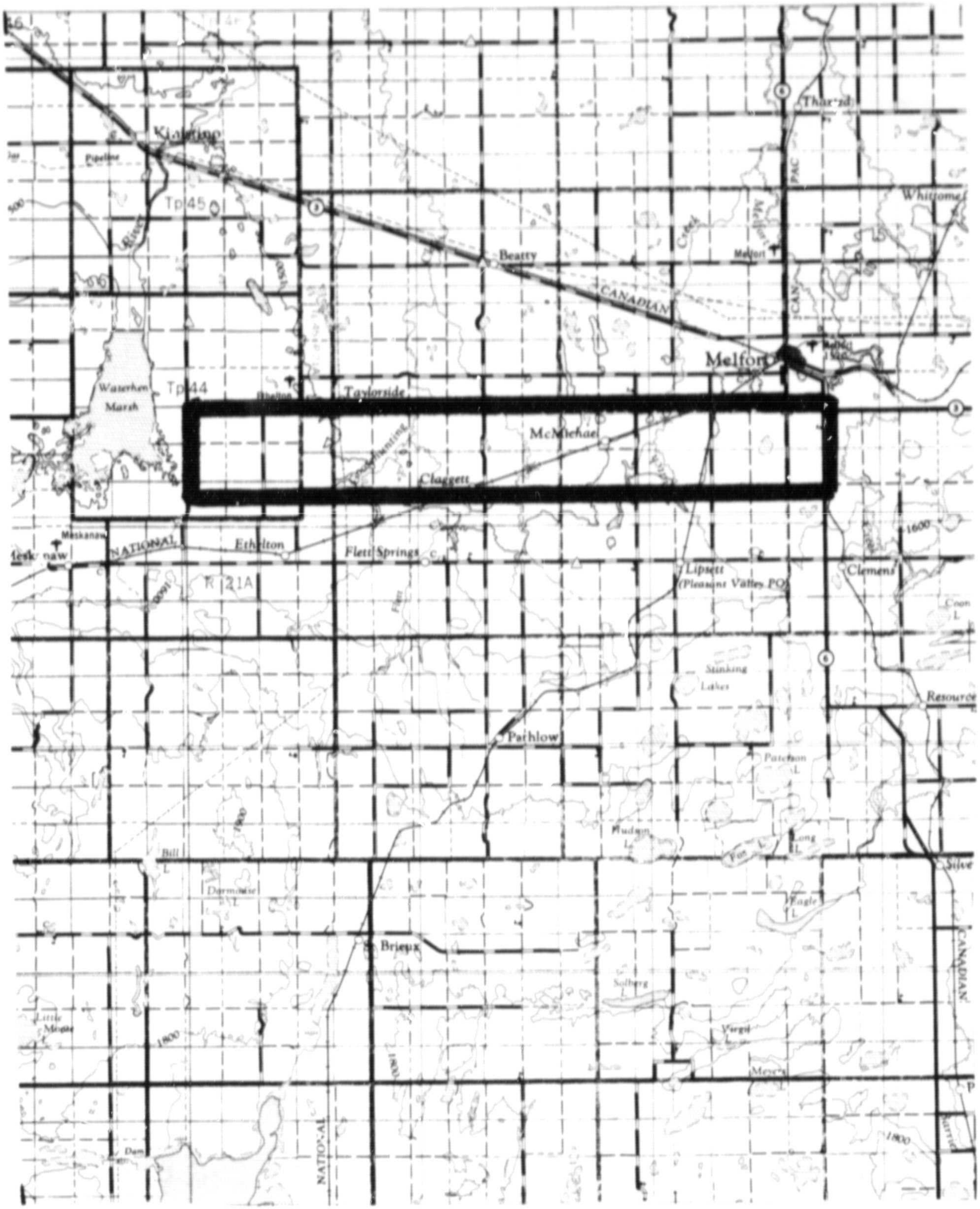

Figure IV-2.- Melfort, Saskatchewan site.

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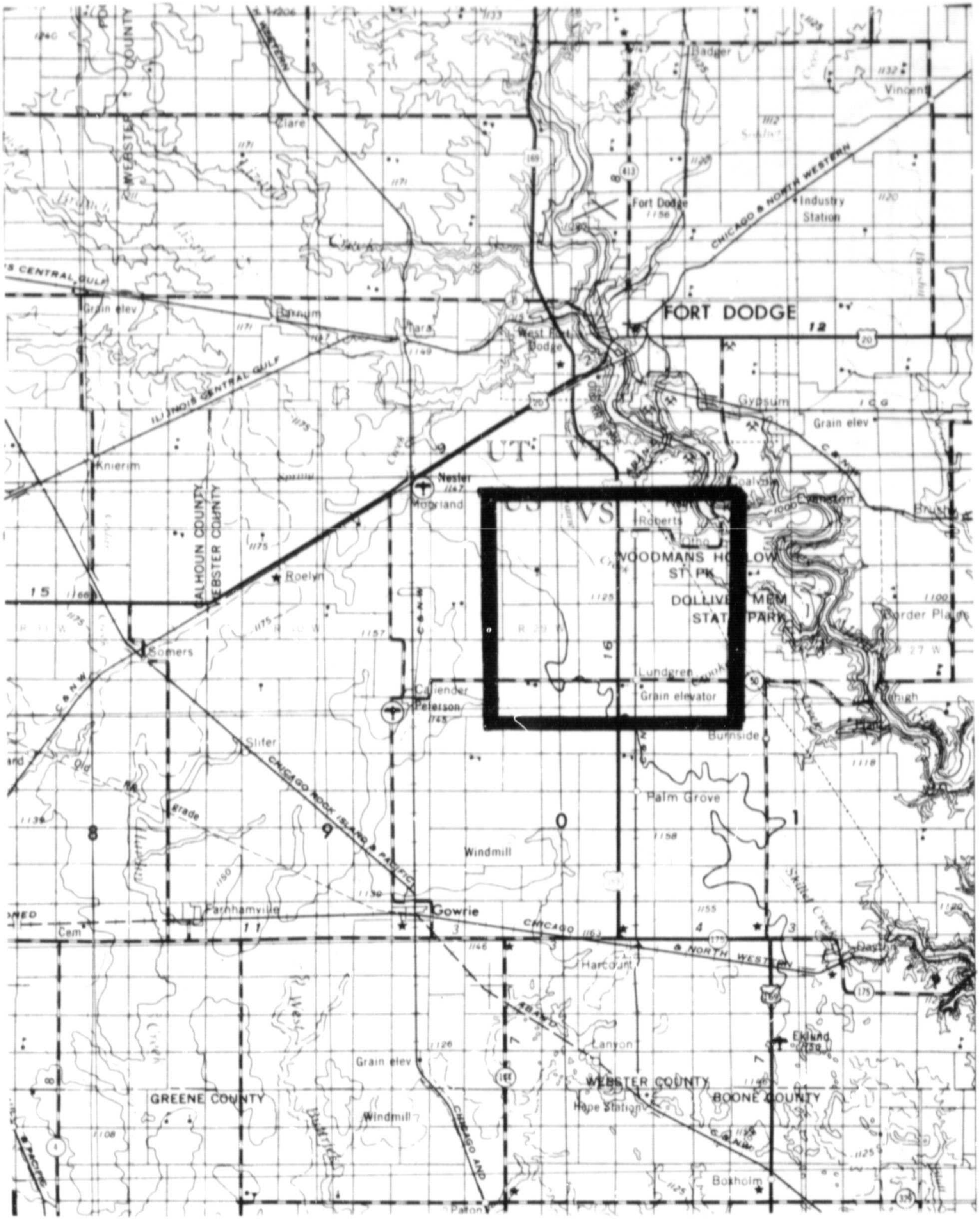

Figure IV-3.- Webster Co., Iowa, site.

5-by-6 nautical miles in size. The area is gridded with N-S and E-W trending roads and field boundaries. The median dates for planting, tasselling, maturity, and harvest for corn are May 10, July 15, September 15, and October 10, respectively. The median dates for planting, blooming, podding, maturing, and harvesting for soybeans are May 25, July 20, August 5, September 20, and October 20, respectively. The median field size for 1980 was 74 acres.

c. Cass County Site

The Cass County site is located in a small grains crop area in southeastern North Dakota near 46°45.0' north and 97°00.0' west. It is similar in shape and size to the Webster County site. No FIREX funds would be expended for the site; it is assumed that planned AgRISTARS Supporting Research (SR) Project and Fundamental Research (FR) Program investigations will continue as is. A site map is shown in figure IV-4.

d. Eudora, Kansas Site

The Eudora, Kansas site is located east of Lawrence, Kansas, and has been extensively studied by the University of Kansas Remote Sensing Laboratory group using the MAS 1-8 GHz, 8-18 GHz and 35 GHz truck-mounted spectrometers, with particular emphasis on soil moisture investigations. There are a number of wheat, corn, sorghum, and soybeans fields which would be studied using the Kansas MAS 1-8 GHz system. The emphasis would be on using ground-based C-band and L-band scatterometers to determine the optimum angles of incidence and polarizations to provide crop identification/condition information along with soil moisture multidate information. A map of the Eudora test site is shown in figure IV-5.

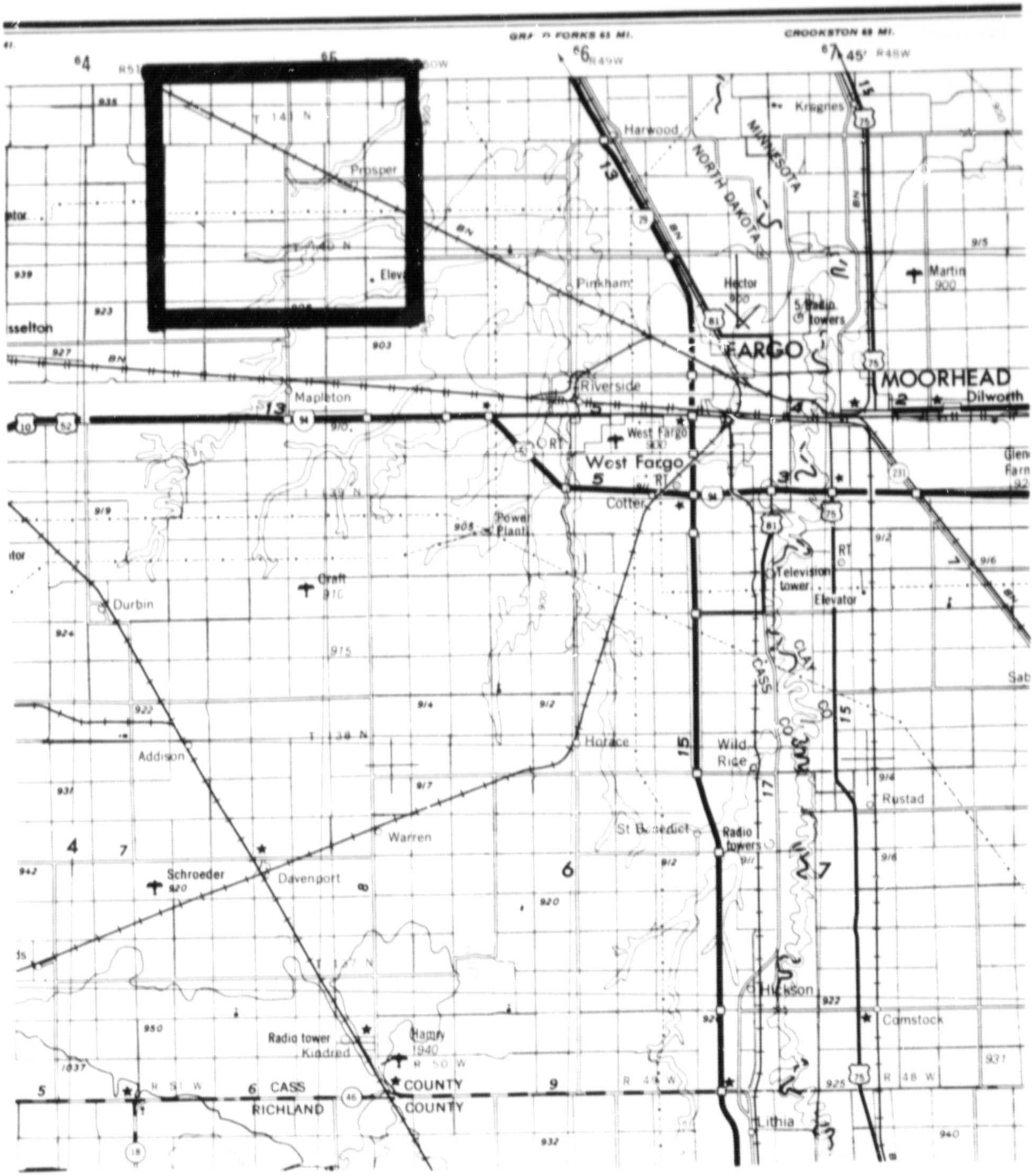

Figure IV-4.- Cass Co., N. Dak. site.

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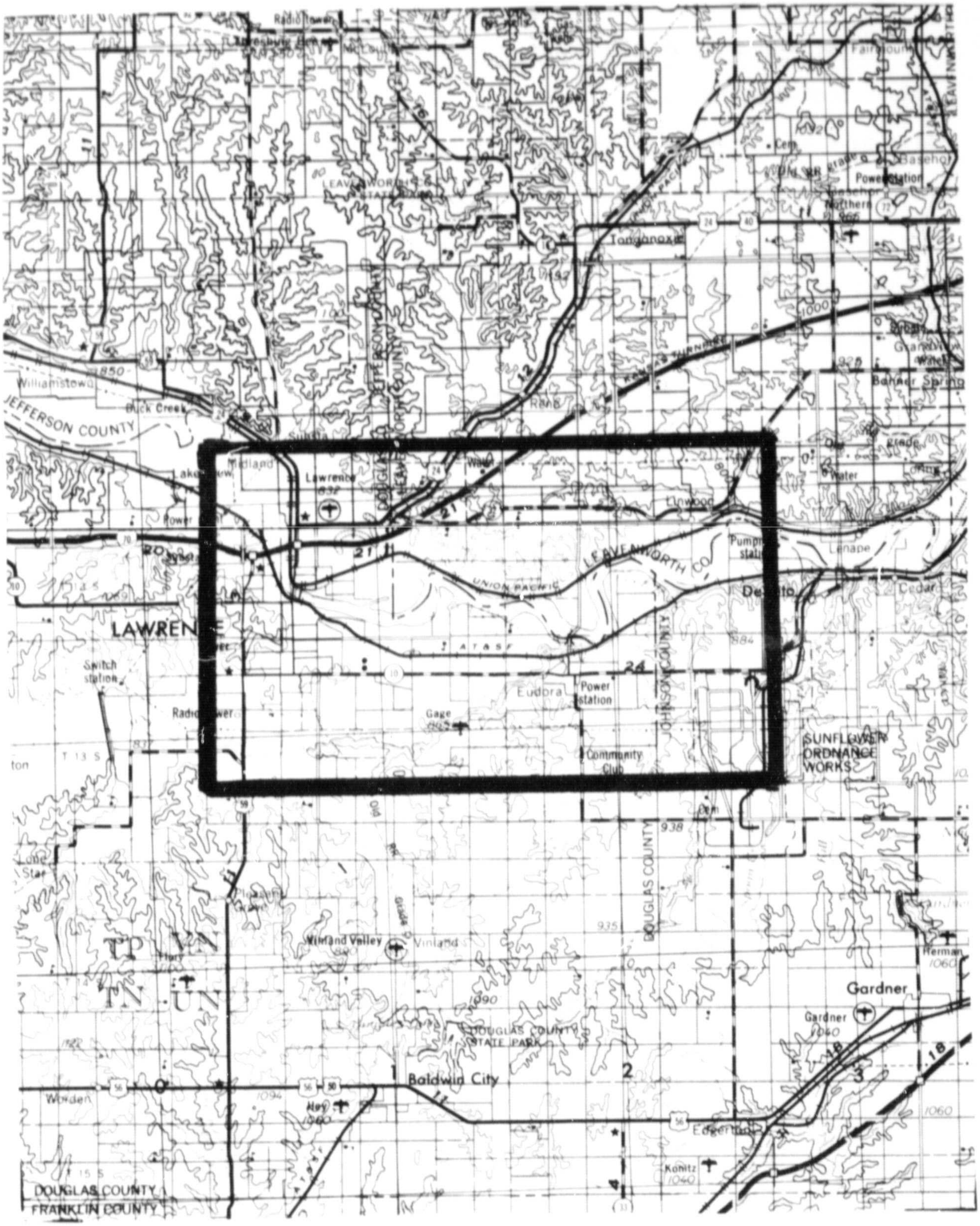

Figure IV-5.- Eudora, Kansas, site.

7. DATA PRODUCTS

a. Webster County and Cass County Sites

(1) Ground-truth Data

As a part of the on-going AgRISTARS SR Project, extensive ground truth is collected periodically throughout the crop growing seasons in each site by the USDA. The general description of these data was given in Section III. The data are summarized into digital data files on computer compatible tape (CCT) by the SR Project personnel. Normally, this task is completed in the spring of the year following the year in which the data were acquired. To accomplish the FIREX study by the end of FY82, these data would have to be assembled by August 1, 1982, for the 1982 season. This would, of course, represent only a partial set as the growing seasons would not be completed for most crops in the areas. The existing planned ground truth data acquisitions in the two sites have a few shortcomings so far as the analysis of radar data is concerned. Additional data are needed on the structure of the surface roughness, on the quantitative moisture contents of the soils, and on the canopy condition. Visible infrared data would be used to estimate leaf-area index (when cloud cover permits). Canopy areal water content (e.g., grams of water per square meter of canopy) and dry biomass density measurements are needed, also. Canopy photographs are needed to document canopy morphology.

(2) Aircraft Data

East-west trending flight lines are shown on the site maps (figures IV-1 and IV-2). These lines run just north or south of access roads in the area and cover the 80 periodic fields sampled by the USDA every week or so as a part of an enumeration. These lines are for low altitude (1500 feet above the ground) runs with the radar scatterometers (L-band HH HV and C-band HH HV) on the NASA C-130. Aircraft photography, infrared radiometer, and microwave radiometer data (L-band and C-band) should be taken, if possible, also, with the scatterometer data to allow documentation of actual aircraft position during the run and the soil moisture conditions. It is essential that photography be taken. Radiometry data are only desired rather than required. Nearly concurrent runs (at 25,000 feet altitude) with the Thematic Mapper Simulator (NS001) on the C-130B are desired, also. This would allow for a determination of the combined and separate roles of TM and SAR data for crop allocations. Flights with the C-130 sensors are required at least nine dates scattered evenly throughout the growing season in each site. It is desirable to have coverage every 18 days. It is necessary to preprocess all of the C-130 sensor system data within one month of acquisition so that data extraction and analysis can be completed by the end of FY82 for those data acquired before September 1 of that year. In FY80 and FY81, aircraft SAR data (X-band only) have been acquired over the sites near or on the dates of the Radar Scatterometer Data acquisitions. The plan for SAR data acquisition using the NASA RB57 aircraft and the NASA/JSC SAR's has been to view the area from the four cardinal directions. The images produced by the east and west looking flights can be compared to the low altitude radar scatterometer data to check SAR calibration accuracy and to provide the basis for calibration correction procedures. In so doing, the absolute (or at least relative accuracy across the image) accuracy of the SAR can be improved so that more fields may be included in the analysis (i.e., those not sensed by the non-imaging radar scatterometer system that collects data down or near the center line of the fields). Such SAR data acquisitions cannot be made in FY82 due to the transfer of these sensors to the NASA CV990 in FY82.

(3) Spacecraft Data

Landsat/MSS data that are acquired on clear days over the test sites should be included in the analysis of FY80-82 aircraft data sets. The Shuttle Imaging Radar (SIR-A) should acquire land L-band SAR data (HH at 40° incidence angles from the nadir) in the fall of 1981 (about September-October) for only 7 days. The SAR data from the SIR-A would be of little use to the FIREX study since the frequency is too low, the incidence angle is too small, and the time of year is after harvest for U.S. crops of interest. Also, it cannot provide meaningful multidate data sets. Thus, the potential use of SIR-A data for FIREX is extremely small and does not warrant the cost involved in its analysis. SEASAT/SAR data were obtained throughout a 6-month period of time in the summer of 1978. These data at L-band (HH at 20° from the nadir) do not hold much promise of utility of crop identification and canopy condition assessment due to the frequency, polarization, and angle of incidence involved. Prospects for soil moisture are better; but, the revisit interval is too long for any practical experiment wherein deeper soil moisture estimates are needed from time-series surface moisture condition data as is obtainable from the SEASAT/SAR data.

B. SOIL MOISTURE

1. OBJECTIVE

The objective of the FIREX Renewable Resources Experimental Program for soil moisture is (1) to refine the choice of optimum incidence angle (within the range of 10-20°) for C-band soil moisture measurement over fields of varying roughness and degrees of vegetation cover, and (2) to determine the usefulness of multidate radar backscatter data for measurement of soil moisture over the growing season. Measurements by the Kansas group (Ulaby, et al.) as well as the French group (Le Toan, et al.) strongly suggest that soil moisture expressed either in terms of percent of field capacity or tensiometrically is strongly correlated with radar backscatter at C-band (4.75 GHz), at an approximate 15° incidence angle. However, additional data are needed to determine correlation coefficients at other low angles (10-20°) and other frequencies (e.g., 5.3 GHz) since a spaceborne C-band SAR may be assigned parameters which are not optimum in the soil moisture measurement sense. Although it is outside of the scope of the proposed experimental program, it is also important to address the problem of the minimum acceptable revisit period (1-5 days) for soil moisture determination. For example, from a satellite altitude of 680 km, a variation in local incidence angle from 7° (near swath) to 17° (far swath) corresponds to a 75 km swath width, which means that in the limit, a revisited swath would have to co-register in ground range to about 8 km or better in order to produce the same local incidence angle to within 1°. Thus, a separate study should be initiated to optimize the specification of revisit interval for the particular problem of orbital SAR monitoring of soil moisture. It is suggested that this issue be addressed specifically by the on-going AgRISTARS Soil Moisture Project in FY82.

2. SCOPE

The proposed research focuses on (1) the determination of optimum C-band radar incidence angle for soil moisture mapping in the presence of varying degrees of surface roughness and vegetation cover, and (2) the measurement of multidate C-band radar data for soil moisture measurement over the growing season. This is within the context of specifying both the optimum angle of incidence for a C-band SAR as well as the critical period through the crop calendar during which accurate soil moisture measurements must be made. Such measurements should ideally be made with using calibrated digitally-processed C-band SAR images; however, this is not available, even with the Canadian CV-580 C-band SAR system, so that the use of a calibrated airborne C-band scatterometer is recommended. It is recommended that the test site for this soil moisture investigation be the Webster County Site.

3. APPROACH

The general technique which is used to understand the best choice for C-band SAR operating parameters for soil moisture mapping is to measure ground truth soil sample moisture by either volumetric means (sample gravimetric percent water plus the sample bulk density) or by the use of a tensiometer, and by correlating these expressions of soil moisture over the top soil layers to the radar backscattering coefficient as measured by both the truck-mounted MAS 1-8 and by the NASA C-130 C-band scatterometer. Both the truck and airborne scatterometers are used to measure σ° versus angle, although the footprint sizes and number of independent samples will generally be different for the MAS 1-8 as compared to the C-130 scatterometer. This measurement is made for a variety of fields, with different surface roughness heights and row spacings as well as different degrees of vegetation cover ranging from base fields to those covered by crops at full maturity and thus of maximum electrical opacity at C-band. The performance criteria include expression of a σ° versus soil moisture level which includes slope, intercept, and correlation coefficient, as related to varying types of fields, surface roughness and degrees of vegetation cover.

Assuming a maximal variability in soil texture (and field capacity) from field to field, a lower limit on necessary resolution for soil moisture mapping would appear to be about 200 m, although simulation studies currently in progress at the University of Kansas will soon refine this number for very realistic agricultural scenes. However, it is important to approach the soil moisture mapping experimental program remembering that fine resolution (e.g., 30 m) from space is probably not necessary, but that sensitivity to intrinsic soil moisture related changes in backscatter and freedom from speckle (e.g., a large number of looks) is necessary. Thus, an understanding of within-the-scene intrinsic variability becomes important in characterizing the performance (resolution and number of looks) of a spaceborne C-band imaging radar.

4. CV-580 SAR DATA REQUIREMENTS

For the same reasons relating to cost of acquisition of the CV-580 SAR data as discussed in the previous sections on Agriculture, there are no plans to acquire CV-580 SAR data over U.S. soil moisture test sites.

5. SUPPORTING DATA REQUIRED

The following data are required for ground truth characterization in support of a soil moisture measurement program:

a. Quantitative gravimetric soil moisture and bulk density measurements (0-10 cm depth) at uniform locations within the field. Oven drying methods should be used.
b. Tensiometer measurements of soil moisture.
c. Soil roughness parameterization on the day of each overflight for each field.

d. Row height, spacing, and general structural shape.

e. Soil textural variations in the field.

f. Height and percent closure estimation of the vegetation cover.

6. SITE LOCATIONS AND DESCRIPTIONS

The Webster County, Iowa, test site was described previously (see figure IV-3).

C. FORESTRY

1. OBJECTIVE

The overall objective of the FIREX Renewable Resources Experimental Program for forestry is (1) to determine the best choice of incidence angle (within a range of 45-60°) at C-band for forest type identification and condition assessment, and (2) to determine the degree to which forest type identification is aided by a dual frequency or dual polarization configuration for FIREX.

2. APPROACH

The approach needed for forestry applications research is to acquire high quality SAR image data at well ground truthed sites at L- and C-band (like and cross polarization). Such data will not be available in the U.S. in FY82.

3. SITE LOCATIONS AND DESCRIPTIONS

a. Kershaw County, South Carolina

The site has been established for the AgRISTARS supporting research/native vegetation study program from FY81 to FY85. Extensive synthetic aperture radar evaluations for forest vegetation will be performed at this site (see attached sheet for the details). Nevertheless, the C-band aircraft SAR was not included in the FY81 full foliage flight mission to be flown during July to October 1981. Since the FIREX base line sensor is a C-band and L-band SAR, it is necessary to conduct a C-band SAR mission during July to October 1981 time frame and in conjunction with the available collateral ground truth to evaluate the C-band SAR data to confirm the results provided by X- and L-band SAR data (see figure IV-6).

b. Clearwater National Forest, Idaho

The site has been established for the AgRISTARS supporting research/native vegetation study program from FY81 to FY85. Main sensor evaluation for AgRISTARS will be the TM Simulator. No SAR experiment will be performed for AgRISTARS. Nevertheless, the available collateral ground truth and the TMS data may help FIREX experiment implementation and evaluation. Comparing with Kershaw County, the site contains different forest vegetation and more terrain slope variations. The aircraft X/C and X/L SAR flight missions are needed for this site to evaluate the results (see figure IV-7).

D. SNOW, WETLANDS, COASTAL LANDS, FLOODING, AND DRAINAGE

A field study could be undertaken to analyze the effect of the radar backscatter coefficient, $\sigma°$, on snowpack characteristics. Snow in the plains and meadows of North Dakota and Minnesota would be overflown in the month of January with a C- and L-band SAR on-board. Also, during January, a NOAA low flying aircraft equipped with gamma ray sensors will overfly Minot, North Dakota (see figure IV-8) to measure snow depth. Ground truth measurements would be necessary for complete analysis of the SAR data. Incidence angles should be 50° or more from nadir because the radar is most sensitive to internal snowpack characteristics at high incidence angles.

Figure IV-6.- Kershaw Co., S. Car., site.

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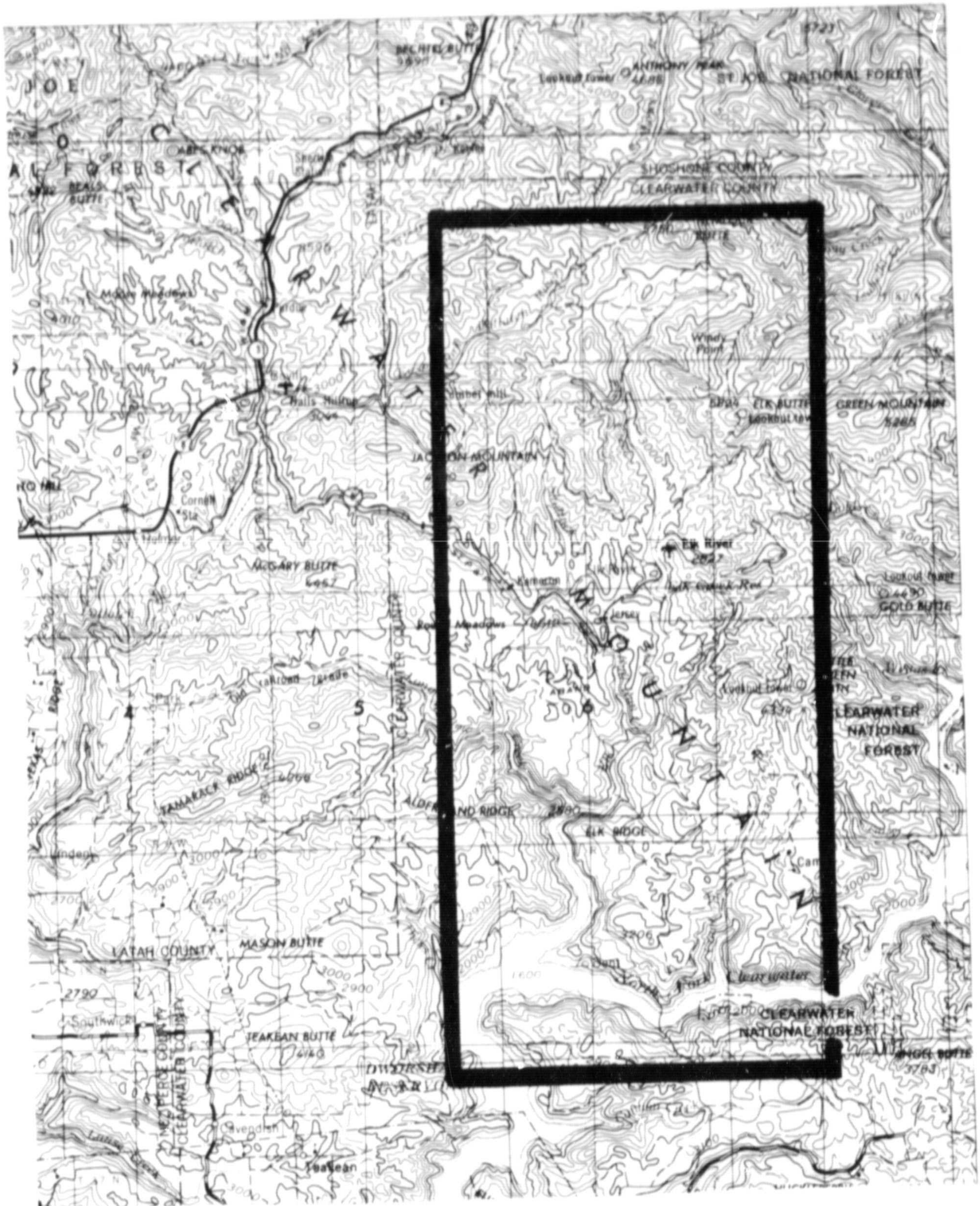


Figure IV-7.- Clearwater Nat'l Forest, Idaho, site.

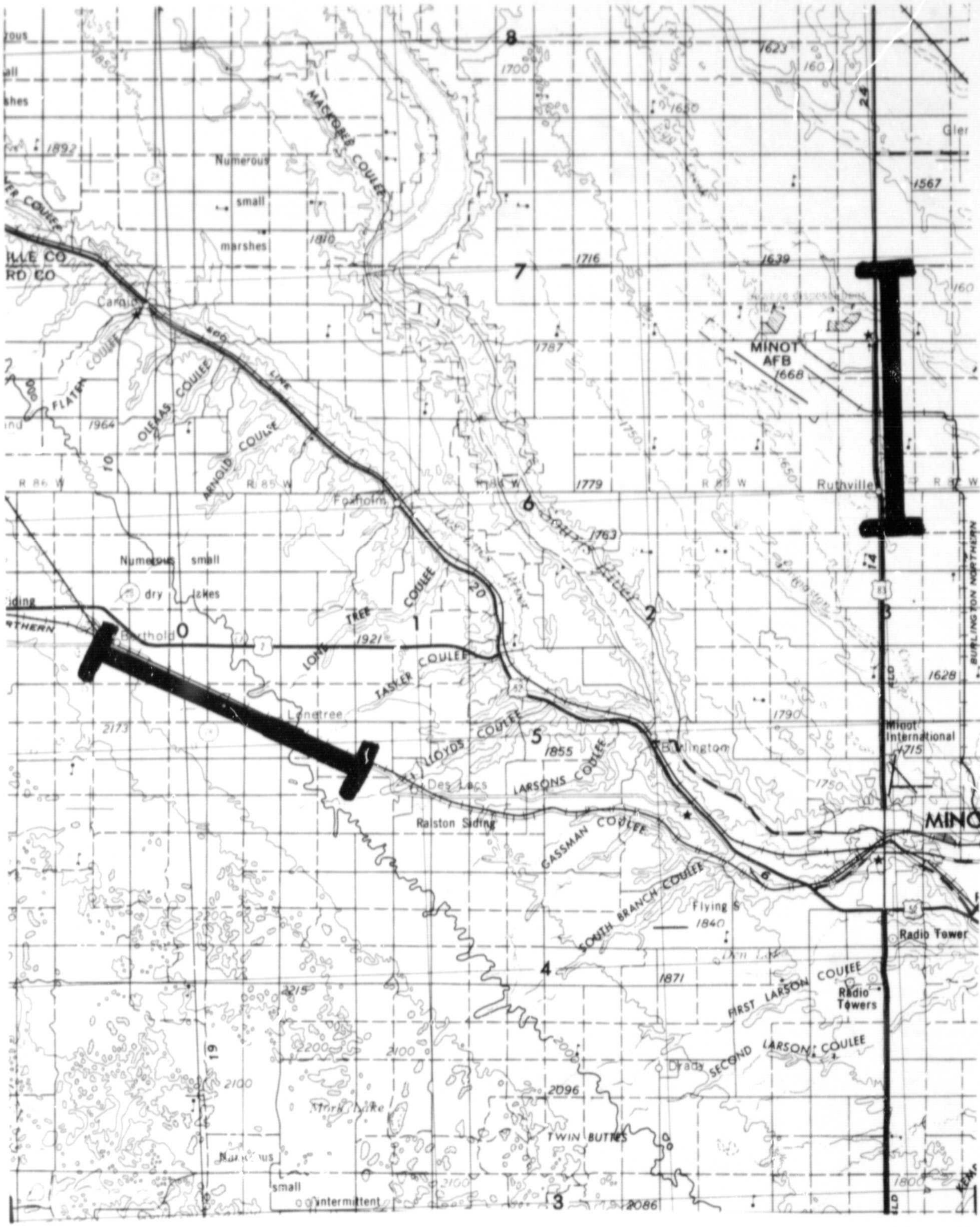


Figure IV-8.- Minot, N. Dak., site.

Expected results would include: determination of the state of the ground beneath the snowpack, assessment of snowpack wetness and determination of snow water equivalent.

A study of wetlands and coastal lands could be made using one test site such as the Pearl River Basin site (see figure IV-9).

The site had been established for the integration of visible, near-infrared, and microwave data research program from FY79 to FY81. Extensive ground truth were available through a concurrent vegetation study as conducted by Dr. David Allen White of Tulane University. Since native vegetation such as marsh shrub and wetland forest within the undisturbed wildlife management area preserve similar vegetation type and configuration for an extended period of time. The ground truth obtained in the past few years still will be valuable for vegetation mapping and extended standing water detection purpose. On the other hand, if there is a need for revisitation of the test site for shoreline change detection, it can be done inexpensively because it is close to NSTL. Both Seasat L-band SAR data and Landsat MSS data were available and can be used to compare with C-band and X-band SAR data. Since FIREX base line sensor is a C-band SAR, the aircraft X/C and X/L SAR flight mission are needed for this site to evaluate the results, particularly to see whether C-band SAR can detect standing water beneath swamp forest using a larger look angle (say 50° incidence angle).

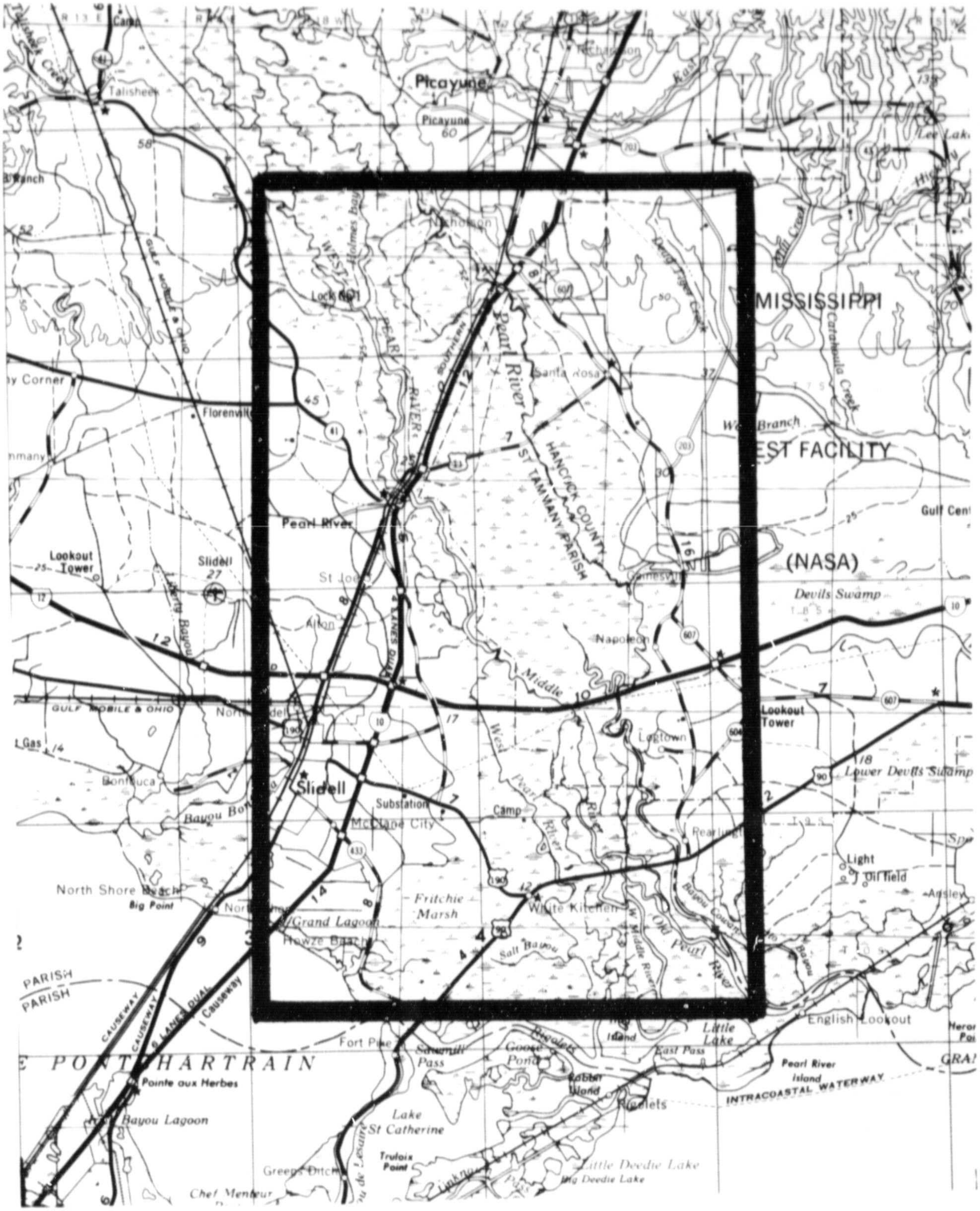


Figure IV-9.- Pearl River Basin, Miss., site.

V. A PROPOSAL FOR A RENEWABLE RESOURCES EXPERIMENT FOR FIREX

SECTION SUMMARY

- This section describes the subset of experiments recommended for funding in FY82, as follows:
  - Melfort, Saskatchewan experiment (small grains identification and condition; CV-580, KU MAS)
  - Webster County, Iowa (corn and soybeans identification and condition and soil moisture; C130B scatterometers, KU MAS)
  - Colby, Kansas, 1978 experimental data analysis
- The expected cost of this program in FY82 is $220,000.

V. A PROPOSAL FOR A RENEWABLE RESOURCES EXPERIMENT FOR FIREX

A. INTRODUCTION

This chapter outlines a proposed set of experiments designed to produce data sets needed in order to optimize the choice of SAR parameters needed for agricultural crop identification/condition and soil moisture mapping. This is a very minimum level ($220K) experimental program which recognizes the severe funding limitations imposed in the NASA budget by a strained economy. However, it is also a minimum program in the sense that at least this much effort must be expended in order to make the investigation worthwhile from the standpoint of articulating the optimum parameters of a spaceborne SAR for use in renewable resource applications. A fractional funding level would not support enough experimental effort to answer such key questions as the additional benefit of a two-frequency SAR over a single-frequency SAR, or a two-angle SAR over a single-angle SAR.

The proposed experiment seeks to make maximum use of other ongoing investigations such as funded through the AgRISTARS or the CCRS program. Indeed, the estimated costs of the individual experiments assume that the NASA/JSC Scene Radiation (microwave) Fundamental Research Proposal will be separately funded at the $50K level and that the University of Kansas will also be funded at the $110K level through the AgRISTARS Supporting Research Project for crop identification/condition research. These amounts ($50K and $110K) are not part of the $220K budget previously mentioned.

The proposed experiment has four parts, which are directed at optimizing the parameters of L- and C-band SARS for both the crop identification/condition problem and the soil moisture mapping problem.

1. Small grains identification/condition, Melfort, Saskatchewan, site.
2. Soil moisture mapping and corn and soybeans identification, Webster County, Iowa, AgRISTARS supersite.
3. Soil moisture mapping and wheat, corn, soybeans, and sorghum identification, Eudora, Kansas, site.
4. Analysis of '75-'77 previously unanalyzed MAS 1-8 GHz data sets for crop identification at C-band.

B. JOINT U.S.-CANADIAN SMALL GRAINS MONITORING EXPERIMENT

1. OBJECTIVES

The major objectives of this experiment are: (a) to evaluate the crop classification accuracy attainable by a C-band radar using multidate observations, with special emphasis on small grains (wheat, barley, sunflower), and (b) to evaluate the capability of C-band radar as a tool for monitoring growth stage and condition of agricultural crops.

2. APPROACH

The proposed investigation will be conducted by a joint team consisting of the Canada Centre for Remote Sensing (CCRS) and the University of Kansas. Two sets of radar sensors will be employed: the CV-580 airborne C-band SAR imager and the University of Kansas truck-based C-band Mobile Agricultural Radar Scatterometer (MARS-C). The cost for the radar image acquisition and processing will be borne by CCRS and the cost for the MARS data acquisition and analysis will be funded by the NASA FIREX activity. Data acquisition by the two sensors will be made at the same site (Saskatchewan, Canada) and at the same time, and the two sets of data products will be shared by both the U.S. and Canadian teams. Of particular significance in this investigation are the following elements:

a. To date, no crop-related experiments have been conducted using a C-band imaging radar. Thus, this experiment will provide the first opportunity to address the objectives stated above with a C-band imaging radar. Crop-classification tests between corn, pasture, wheat stubble, and using C-band scatterometers have shown accuracies in the 80% range; this is based on C-130 flights over the Colby, Kansas, test site in 1978.

b. The MARS-C can be used to calibrate the C-band images in terms of the radar scattering coefficient so that classification and analysis techniques may be applied to all fields contained in the imaged swath, which may not be possible otherwise.

c. The MARS-C serves to independently verify the crop classification and condition assessment results obtained by the C-band images.

d. The approximately 2-day revisit interval provided by the MARS-C for a limited number of fields (approximately 60) can be used to better define the needed revisit interval for a space SAR than can be done with an airborne imager (unless flown that often which would be prohibitive in cost).

Experiments conducted at frequencies above 8 GHz by the University of Kansas and by the Paul Sabatier University, Toulouse, France, have shown that the radar temporal response of wheat is characterized by two pronounced cycles, as demonstrated in figure V-1. The scattering coefficient behavior during the first cycle (Julian date 100-150) is associated with the green leaf area index

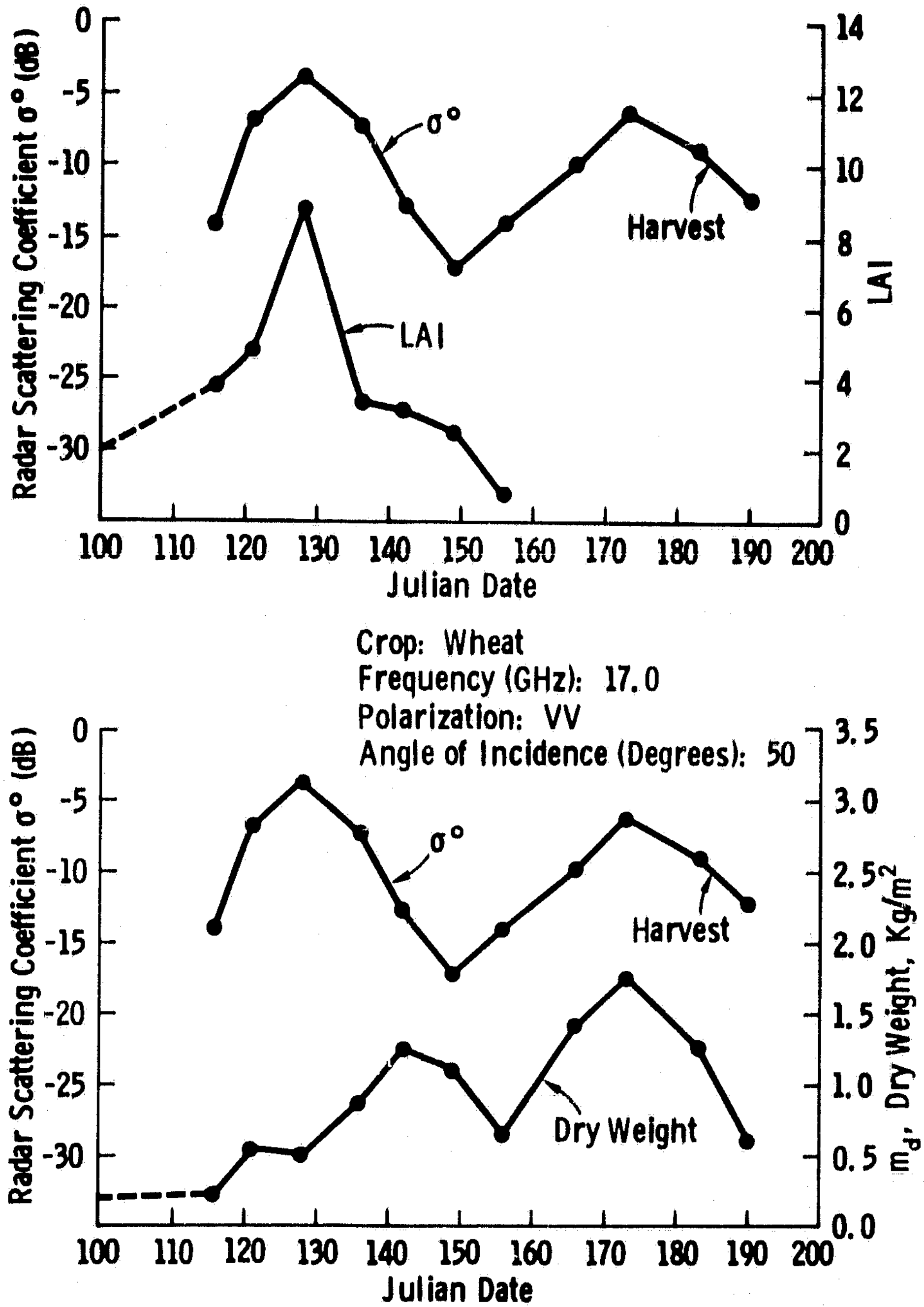


Figure V-1.- Multidate variations of σ°, Leaf Area Index (LAI) and Canopy Dry Mass m_d of Wheat (1980).

or the canopy water content (these two parameters are highly correlated), while the second cycle (Julian date 150-180) is associated with the dry matter content which is primarily in the wheat heads. It has been postulated that the magnitude of the change = the radar scattering coefficient between the dip between the two cycles (Julian date 150) and the peak of the second cycle is directly related to the mass of wheat heads per unit area, and therefore to yield. The proposed investigation is aimed at testing this interpretation at C-band and L-band.

3. EXPERIMENT DESCRIPTION

a. Test Site

The experimental site is the LACIE site near Melfort, Saskatchewan. This area has been extensively documented and has been used for remote sensing agricultural studies for a number of years. The site is also a representative crop mixture of cereals, oilseeds, summer fallow and forage crops.

b. Sensors

(1) CV-580 C-band radar imager.

(2) University of Kansas C-band radar scatterometers (MARS-C).

The truck-mounted MARS-C system will be transported from the University of Kansas in Lawrence, Kansas, to the test site where it will be used for approximately 2 months and then transported back to Lawrence, Kansas.

c. Ground-Truth Data

In addition to crop type, field characteristics, stage of growth, and yield information, which will be obtained for a large number of fields (in excess of 100), plant and soil samples will be gathered periodically from representative fields to measure their moisture contents. Also, meteorological information will be obtained.

d. Data acquisition, processing, and distribution

The overall experiment plan and operation will be coordinated by the joint U.S.-Canadian team. CCRS will be the principal group responsible for the acquisition and processing of the CV-580 C-band imagery and the ground-truth data, and the University of Kansas will play a similar role with the regard to the MARS-C data. All data acquired in conjunction with the experiment will be shared by both groups, and final analysis and results will be published in a joint report.

4. RESOURCES

As mentioned above, the following sensors are needed for this investigation:

a. CV-580 C-band SAR (Canada)

b. C-band Mobile Agricultural Radar Scatterometers (MARS-C).

5. COSTS

Cost for the U.S. (University of Kansas) portion of this investigation is estimated to be $60K. This includes transport of the MARS-C system to and back from the test site (Saskatchewan, Canada), data acquisition for 2 months, data processing and analysis.

6. SCHEDULE

ACTIVITY	FY82		
	1	2	3
Transport MARS-(C) to site		—	
MARS Data Acquisition			—
CV-580 (SAR's, SCATS) Flights			—
MARS Data Processing			—
CV-580 Data Processing			—
Data Analyses			—
Final Report			▼

C. WEBSTER COUNTY, IOWA, CORN AND SOYBEANS EXPERIMENT

1. OBJECTIVES

Relative to the use of a FIREX system to identify corn and soybeans and to assess corn and soybean canopy conditions, the objectives of this experiment are to determine the optimum angle of incidence and the relative effect of changing incidence angles over the range from 45-60° and to determine the degree to which performance is improved when a dual frequency (L- and C-band) or a dual polarization configuration is used as opposed to a single C-band like polarized configuration. These performance issues will be evaluated versus the costs of the FIREX system. Multidate data will be used. Comparisons will be made with and without Landsat/MSS or Thematic Mapper Simulator Data.

2. APPROACH

To meet the objectives, it is proposed that existing L- and C-band data acquired in the Webster County, Iowa, AgRISTARS supersite be analyzed empirically to determine the separability of corn and soybeans on the specific dates on which the radar scatterometer data were acquired by the NASA C-130. Also, it is proposed that a FY82 set of multidate C-band and L-band radar scatterometer data be acquired over the site to serve as a basis for crop identification and canopy condition assessment studies for FIREX. In addition, it is proposed that the University of Kansas 1-8 GHz Microwave Active Spectrometers (MAS 1-8) be used to acquire data from about 50 fields in the test site, with a 3-day revisit period, over the April-June experiment duration.

Since the L- and C-band airborne scatterometers acquire data at angles from 5-50° simultaneously, in addition to using the 40° and 50° data for the applications discussed above in connection with crop classification and wheat yield, the data in the 10-20° range can be used to further refine previous results that show C-band radar to provide good soil moisture estimates for bare and vegetated-soil conditions alike. This type of result has been found by the University of Kansas and USDA in the U.S. and by two independent groups in France.

3. EXPERIMENT DESCRIPTION

As a part of the AgRISTARS Supporting Research Program, L-, C-, and Ku-band scatterometry data were acquired in two test sites in 1980. These data are for L-band HH and HV, C-band HH and HV, and Ku-band VV. The data were acquired for angles from 5-50° although further processing could yield data at angles up to 65-70°. At the Cass County site in North Dakota, data were acquired over wheat, barley, and sunflower fields on May 12, 1980 (before planting), and on August 13, 1980 (near harvest). At the Webster County site in Iowa, data were acquired over corn and soybean fields on August 19, 1980 (flowering and seed development), and on September 10, 1980 (maturity). The L- and C-band data have not been analyzed.

In FY81, four scatterometer data acquisitions are planned for the Cass County site. None is planned in the Webster County site due to limited resources in this year's AgRISTARS program.

The data acquisitions in the Cass and Webster County sites are as part of a much larger effort in which periodic ground truth data are acquired during the growing season to support Landsat/MSS, aircraft Thematic Mapper Simulation (NS001), and helicopter Field Spectrometer System (FSS) measurements and related analyses. Landsat/MSS data are acquired every 18 days weather permitting; FSS data are acquired eight times during the growing season, and NS001 data are acquired six times during the season. Ground truth is collected by USDA personnel and consists of crop type, acreage planting date, emergence date, harvest date, yield, production, row direction, row width, and certain periodically obtained data, height, ground cover, canopy appearance, growth stage, surface soil moisture, damage, weediness, and fertilizer and pesticide applications. The farmers make daily observations of rainfall as well at 23 locations in the 5-by-6 nautical mile test sites. High altitude photography is obtained of each site at least once per year to aid in preparation of field boundary maps.

Relative to the radar data analysis, several shortcomings exist in the Cass and Webster County sites. No canopy conditions measurements such as leaf area index, biomass, nor canopy moisture content are made. Also, soil moisture is not measured quantitatively. Rather, a subjective estimation of surface soil moisture condition is made based on how the soil feels to the human touch. In addition, row height and surface roughness are not noted.

Nevertheless, these existing data sets (1980-81) should be used to address the specific issues of best incidence angle and utility of L- and C-band and/or of like and cross polarization data for crop identification. Crop canopy assessment cannot be evaluated based on these past data sets since canopy condition was not measured as a part of the ground truth data.

The effort in FY82 shall be to extract L- and C-band airborne C-130 radar scatterometer data for specific fields from which ground truth data were acquired, to use these data as features in classification schemes (clustering and maximum likelihood classification) for identifying corn and soybean fields, and to evaluate the results thereof. This work shall be done by the LEMSCO support contractor for NASA/JSC.

In FY82 also, another set of radar scatterometer data shall be acquired over the Webster County site during the growing season. Nine flights are required and should be spaced out evenly between just after emergence to just before maturity. Four of these flights are already planned under the existing AgRISTARS Supporting Research Program. Thus, five of these flights represent additional requirements. If funded under the Fundamental Research Program, a local university will collect crop canopy condition and soil moisture condition data in the 80 fields during the FY82 aircraft overflights. Under the existing AgRISTARS Supporting Research Project, the USDA periodically measures crop height, canopy cover, and row width. Also, estimates are made of surface soil moisture conditions, damage, and weediness. Crop type and crop stage of development are noted. Also, once per season, data are obtained on yield, planting date, emergence data, harvest date, and applications of fertilizers and pesticides.

4. RESOURCES

Nine flights with the C-130 aircraft are needed in FY82 from June 1 to September 15. L- and C-band radar scatterometer, Thematic Mapper Simulator, and aerial photography data (with color infrared film) are needed on these flights. All data processing needs to be completed and data products sent to the investigators within one month of acquisition to allow time for analysis of the data in time for the FIREX Study Final Report.

Lockheed Engineering and Management Systems Company (LEMSCO) personnel are needed at NASA/JSC to perform the tasks of data registration, editing, correction, and analysis.

Under Fundamental Research Program funding, a ground truth contractor is needed to supplement the existing ground truth collected by the USDA as a part of the AgRISTARS Supporting Research Project activity in the site.

5. COSTS

Activity	Provider	Costs to FIREX
Baseline ground truth data acquisition (FY82)*	USDA	-0-*
Aircraft data acquisition and preprocessing (FY82)	NASA	-0-
Supplemental ground truth (canopy condition and quantitative soil moisture during flights) (FY82)**	Iowa State	-0-**
Aircraft Data (FY80-82) registration, editing, and analyses (FY82)	LEMSCO	$50K
MAS data acquisition, processing, and analyses	KU	40K
TOTAL (FY82)		$90K

6. SCHEDULES

Activity

Analyze FY80 and FY81 C-130 SCAT and RB57 X-SAR Data

Select Ground Truth Contractor for FY82

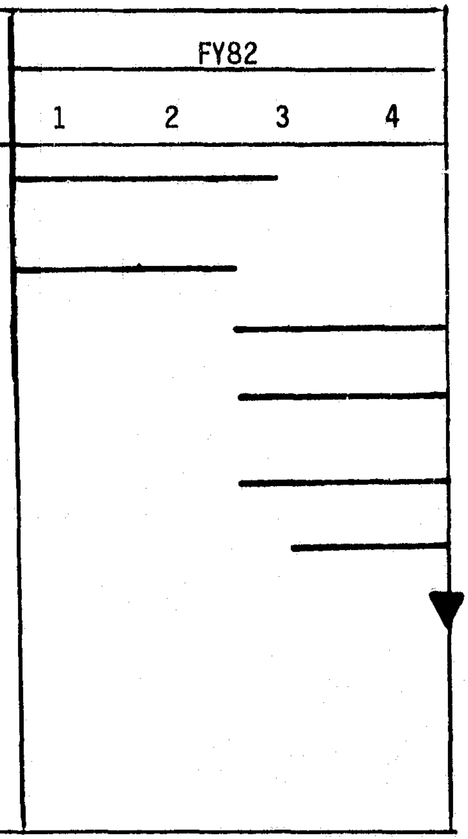
C-130 (SCAT, TM) Flights

Ground Truth Data Processing (USDA and special supplement)

C-130 Data Processing

Data Analyses

Final Report



* AgRISTARS Supporting Research Project funded.
**Fundamental Research Program funded.

Activity	FY82			
	1	2	3	4
Complete Experiment Design				
MAS 1-8 Data Acquisition				
Ground Truth Data Acquisition				
MAS Data Processing				
Ground Truth Data Processing				
Data Analyses				
Final Report				

D. <u>ANALYSIS OF '75-'77 MAS 1-8 DATA</u>

1. OBJECTIVE

The objective of the analysis of the 1975-77 MAS 1-8 data acquired at the University of Kansas test sites is to determine the optimum angle of incidence and the improvement afforded by the use of a dual frequency and/or dual polarization configuration for FIREX as compared to a C-band like polarization system for crop identification and crop condition assessments.

2. APPROACH

MAS 1-8 data were acquired for HH, HV, and VV polarization combinations, for angles of 0-50° from nadir, and for corn, sorghum, soybeans, and wheat during the 1975-77 growing seasons for a set of soil moisture experiments. These data were never analyzed for the purpose of crop identification and canopy condition assessment since higher frequency data (8-18 GHz) were acquired also and were used for that purpose. Data were obtained on the canopy moisture content and morphology during the experiments.

These data shall be examined to address the specific issues of incidence angle effects and the utility of dual polarization and dual frequency. Linear discriminate classification will be used with data set grouped by crop type and field. Randomly chosen fields will be used as training fields for the classifier, and the classification procedure shall be tested on randomly selected test fields.

3. EXPERIMENT DESCRIPTION

No new experimental data will be collected for this experiment. Thus, it is not necessary to describe the experiment.

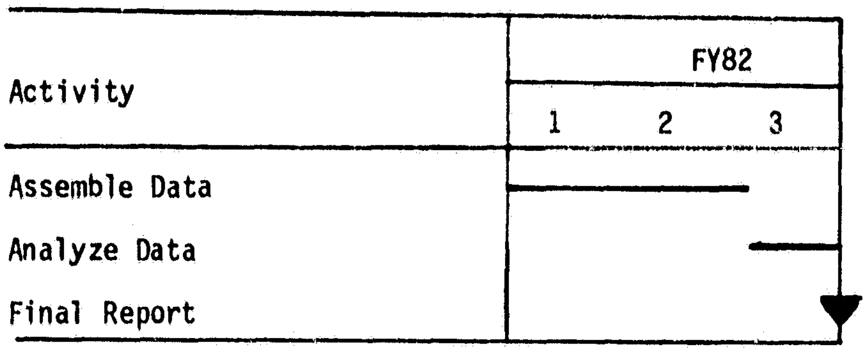
4. RESOURCES

Since the ground-based radar scatterometer data (MAS 1-8) and ground truth data exist and need only to be analyzed for the specific FIREX issues, the only resources required are for personnel to analyze these data.

5. COSTS

Task	Provider	Estimated Cost
Analyze the 1975-77 MAS 1-8 data for crop identification and crop condition assessment	KU	$25K
TOTAL		$25K

6. SCHEDULE



E. COST SUMMARY

Saskatchewan Experiment	JSC/KU	$60K
Webster County, Iowa, Experiment	JSC/LEMSCO/KU	90K
1975-77 MAS 1-8 Data Analyses	JSC/KU	25K
C-130 SCAT Data Acquisition Proc.	JSC/LEMSCO	45K
TOTAL		$220K

VI. A SCENARIO FOR FIREX INFORMATION EXTRACTION

VI. A SCENARIO FOR FIREX INFORMATION EXTRACTION

The purpose of this section is to look ahead to the time when a FIREX system is placed into Earth orbit and is acquiring data. At that time (late 1980s), most of the research into the information content of visible and infrared satellite systems such as the Landsat/MSS, TM, and the French SPOT will be completed and much of this understanding will have led to several important operational survey satellites financed by consortiums of user groups. These operational systems will have gone through a satellite research phase during which concepts developed from aircraft- and ground-based systems have been tested and refined with data collected over hundreds of study sites at regular revisit intervals and for many years.

In the meantime, a relatively low level of effort in microwave sensing will have been proceeding with ground- and aircraft-based sensor data supplemented by an occasional spacecraft system such as the Shuttle Imaging Radar. It is important to realize that the advent of a long-life free-flying SAR in multiconfigurations (angles, frequencies, and/or polarizations) will present a totally new dimension to microwave research -- the availability of regular, multidate, twice-daily, high resolution radar image data over all land and sea areas (at least, over a large fraction of the surface of the Earth).

Let us imagine, therefore, the uses that these data could be put to for research purposes and eventually for operational purposes on a future, privately financed satellite.

A. CROP IDENTIFICATION AND AREA ESTIMATION

A FIREX system will acquire high resolution radar image data at 45°-60° incidence angles at 10-day intervals. If our present ideas hold true, the data will be acquired at C-band and L-band for VV polarization plus an additional channel or two (C-band VH and/or L-band VH). Only a small portion of the cropland areas of the major crop producing countries of the world would be used for research into the uses of FIREX system data for crop identification. An approach similar to LACIE and AgRISTARS will probably be adopted in which small segments scattered randomly through large cropland regions will be used as the basis for crop identification, crop area estimation, and crop proportion estimation. For each segment, it will be necessary to register the FIREX image data to Landsat or SPOT image data and to register both to a ground-based map used for ground truth data. The accuracy of this registration should be to within a pixel or better to reduce classification errors caused by misregistration. Thus, FIREX image data will become a subset of an overall set of remotely sensed image data to be used for crop identification and crop area proportions estimation. It will be the annual sequence of information in this combined data set throughout the growing season that will provide the bases for sufficiently accurate crop area estimations. Multiband (visible, infrared, microwave) classification schemes such as CLASSY will be used. The greatest results will probably come from profile estimation schemes where parameters representing the annual rate of greenup and maturity of crops will be used as primary discriminant features. Radar data will provide data continuity for those visible and infrared data sets that are not acquired due to clouds. In late season, evidence thus far indicated a response in the microwave backscattering to dry matter production in the reproductive (fruit) stages that cannot be seen in visible and infrared data.

B. CROP AND SOIL CONDITION ASSESSMENT

After a field has been identified by crop type and its area has been measured, remote sensing data can be used to monitor its vigor and to aid in the estimation of grain yield. Modern physiological crop yield models simulate the daily progress in plant processes leading ultimately to grain yield. These models require several types of input data such as planting date, crop/cultivar type, fertilizer application dates and amounts, daily rainfall, daily temperature, and soil type parameters. The models make estimates of daily evapotranspiration, root extension, carbon reservoir, photosynthesis, leaf extension, and so on. Some model predictions such as surface soil moisture, leaf area index, and dry and wet biomass production can be checked independently by canopy and soil measurements based on remote sensing inputs. Departures could be used to adjust model parameters such as planting date, cultivar types, fertilizer application, and soil depth. Direct indicators of plant water stress such as lowered canopy moisture content in the afternoon and air-canopy temperature differences could be used to infer crop yields. All of these uses rely upon multispectral data and not on one type of spectral data alone.

C. FOREST MANAGEMENT

Visible and infrared data have been used to identify forest species, to map forest types, and to assess forest canopy conditions. The addition of SAR data should allow for greater discrimination and for a better assessment of forest canopy moisture conditions. Since many forests are located on unlevel ground, SAR data will have to be corrected for local slope angle effects. Digital terrain data bases exist and techniques exist to allow for correction of apparent backscattering coefficient data for local slope effects so as to allow one to use the change in the magnitude of backscattering to estimate changing moisture conditions.

D. SNOW, WETLANDS, COASTAL LANDS, FLOODING, AND DRAINAGE

The C-band FIREX data should give information on snowcovered area; this will augment the passive microwave and Landsat data from which snowcovered area can presently be determined. Of course Landsat data are severely restricted by the Landsat revisit cycle and cloud cover, and passive microwave data are restricted by the poor resolution. The radar data should allow snowcovered area and water equivalent measurements to be made regardless of weather conditions, and in forest clearings and numerous points across a watershed for translation to large areas.

In regard to flooding and drainage, the radar will offer valuable flood information without regard to cloud cover at a resolution that should be very useful for local planning authorities to determine flood damage estimates and flood hazard zones.

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REFERENCES

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APPENDIX A

EXISTING DATA SETS

APPENDIX A

EXISTING DATA SETS

Although much is known about the radar backscattering properties of land cover types involved in renewable resources (crops, soils, forest, wetlands, coastal zone land, snow, and water), several specific and important issues remain with respect to the FIREX system design. These issues have been defined in the Section III above. The Renewable Resources Study Team designed an experimental program plan to be implemented during the remainder of FY81 and in FY82. The plan, described in Sections IV and V, addresses the specific research issues defined in Section III so far as the limited time and available resources permit. The nature of existing complementary data sets is described in this appendix.

A. PRE-LAUNCH RESEARCH SUPPORTING DATA REQUIREMENTS (FY81-82 ONLY)

1. AGRICULTURE

a. Existing Ground-Based Complementary Data Sets for FIREX:

Since 1972, the University of Kansas has acquired radar backscattering data for a number of different crops during the growing season in small plots mostly in Kansas. A brief description of the nature of these sets is given below for each year. These data constitute the only U.S. ground-based active microwave backscattering measurements from crops.

(1) 1972 experiment -- Measurements were made with the MAS 4-8 (4-8 GHz), HH, HV, VV, and VH for angles of 0-70° in August only for corn, milo, alfalfa, and soybeans. The results from this experiment were published in reports by Ulaby

and Moore (1973) and Ulaby (1973). Dual frequencies and dual polarization were recommended with angles above 40°.

(2) 1973 experiment -- In 1973, MAS 8-18 was operational and was used to make frequent measurements over corn, sorghum, soybean, and alfalfa fields for HH, HV, VV, and VH and for angles from 0-70°. The revisit interval was about 3 days. The results of this experiment were published in a report by Ulaby et al. (1974). They observed no significant difference between HH and VV so far as the back-scattering properties of crops were concerned. Also, angles from 30 to 65° showed best results for crop applications.

(3) 1974 experiments -- The MAS 8-18 was used again for HH and VV only and for angles of 40-70° only. The system was used on corn, alfalfa, wheat, sorghum, soybeans, and bare soil with a revisit interval of about 7 days. These data were used to construct simulated radar images every 5 days. The results of this experiment were reported by Ulaby and Bush (1975a and 1975b), Bush and Ulaby (1975), Bush and Ulaby (1978), Bush and Ulaby (1976), and Bush et al. (1975). Based on these data, it was concluded that the moisture content of corn and wheat canopies could be estimated from 8-18 GHz $\sigma°$ measurements at large incidence angles (40-70°). Also, rain-caused morphological changes on soybean canopies showed some radar response. The seasonal range in $\sigma°$ at high angles for soybeans and milo was small (~ 2 dB). Studies of the effect of revisit interval on crop classification accuracy showed that a revisit of <10 days is needed. Another experiment at College Station, Texas, with the MAS 2-8 was carried out with a hybrid of sorghum. The objective was to sense soil moisture changes and surface roughness change through the canopy (height was

90 cm or greater). The results of this experiment are reported by Ulaby and Batlivala (1975). The data exhibited little response to soil moisture changes under the thick canopy; therefore, the backscatter was mostly that from the canopy itself even at the relatively low frequencies and angle of viewing. Unfortunately, the duration of the experiment was short (2 weeks) so that the canopy did not change much in its agronomic characteristics. Interesting diurnal effects were observed especially at the lower frequency end in which nighttime σ°'s at 2.75 GHz and 50° HH.

(4) 1975 experiment -- This year the MAS was expanded to the full 1-18 GHz range with HH, HV, and VV and for angles of 0-80°. Corn, sorghum, soybeans, and wheat were observed over the growing seasons. The results of this experiment are given in Dobson et al. (1977). Row direction effects were studied for vegetated fields. It was concluded that row direction produces no effects on σ° when frequencies of 4 GHz or higher are used. This conclusion is valid for vegetated fields only.

(5) 1976 experiment -- The MAS 1-8 and MAS 8-18 were used for HH, VV, and HV and for angles of 0-50° (MAS 1-8) and 0-70° (MAS 8-18) for alfalfa, brome, clover, corn, sorghum, oats, soybeans, and wheat. These data are reported in a report by Dobson et al. (1978). A report was prepared by Ulaby et al. (1979) in which the results of the 1974-76 experiments were presented. This study showed year-to-year consistent crop classification results in which multidate radar data produced excellent classification results (>90%) except for alfalfa and sorghum.

(6) Data for FIREX study -- As stated before, most data acquisitions by the University of Kansas have been in the 8-18 GHz range for crops--a range not usable for FIREX. The 1975-76 experiments included data in the 1-8 GHz range for corn, sorghum, soybeans, and wheat and for angles of 0-80° with HH, VV, and HV. These data taken during the entire growing season of each crop can be used to address the technical issues of the effects of angle (45-60°), frequency (L- and C-band), and polarization (like and cross). The 1976 data is limited to 0-50° in the 1-8 GHz range.

3. EXISTING AIRCRAFT-BASED COMPLEMENTARY DATA SETS FOR FIREX

a. SAR Data

A considerable amount of X-band SAR images have been produced over cropland. These are not discussed here since FIREX cannot operate at X-band or higher frequencies. An analysis was made of a September 13, 1973, L-band SAR image (HH and HV) of fallow, pasture, grass, woods, corn, and soybeans at an angle of 43° (Ulaby et al., 1980). Classification results were fair (60% for HV; 65% for HH; 71% for HH plus HV). No C-band SAR images have been acquired over cropland.

b. Scatterometer Data

P-, L-, C-, and Ku-band scatterometers were acquired over a test site near Colby, Kansas, on July 18-22 and August 8-11, 1978, as a part of the Agricultural Soil Moisture Experiment (ASME). A report was written by Ulaby et al. (1981) on the results of using the July 18 and 20 Ku-band VV data at 50° only for land cover classification. These data were used with and without Landsat/MSS data acquired on July 26, 1978. The L- and C-band data have not been analyzed.

As a part of the AgRISTARS Supporting Research Program, L-, C-, and Ku-band scatterometry data were acquired in two test sites in 1980. These data are for L-band HH and HV, C-band HH and HV, and Ku-band VV. The data were acquired for angles from 5-50° although further processing could yield data at angles up to 65-70°. At the Cass County site in North Dakota, data were acquired over wheat, barley, and sunflower fields on May 12, 1980, (before planting) and on August 13, 1980 (near harvest). At the Webster County site in Iowa, data were acquired over corn and soybean fields on August 19, 1980 (flowering and seed development) and on September 10, 1980 (maturity). The L- and C-band data have not been analyzed.

In FY81, four scatterometer data acquisitions are planned for the Cass County site. None are planned in the Webster County site due to limited resources in this year's AgRISTARS program.

The data acquisitions in the Cass and Webster County sites are as part of a much larger effort in which periodic ground truth data are acquired during the growing season to support Landsat/MSS, aircraft Thematic Mapper Simulation (NS001), and helicopter Field Spectrometer System (FSS) measurements and related analyses. Landsat/MSS data are acquired every 18 days weather permitting; FSS data are acquired eight times during the growing season, and NS001 data are acquired six times during the season. Ground truth is collected by USDA personnel and consists of crop type, acreage planting date, emergence date, harvest date, yield, production, row direction, row width, and certain periodically obtained data, height, ground cover, canopy appearance, growth stage, surface soil moisture, damage, weediness, and fertilizer and pesticide applications. The farmers make daily observations of rainfall as well at 23 locations in the 5 × 6 nautical mile test sites. High altitude photography is obtained of each site at least once per year to aid in preparation of field boundary maps.

Relative to the radar data analysis, several shortcomings exist in the Cass and Webster County sites. No canopy conditions measurements such as leaf area index, biomass, nor canopy moisture content are made. Also, soil moisture is not measured quantitatively. Rather, a subjective estimation of surface soil moisture condition is made based on how the soil feels to the human touch. In addition, row height and surface roughness are not noted. Finally, the radar data should be acquired more often (six times per site each season) and in each site to allow for a better understanding of multidate data information content. It would be highly desirable to obtain data every 10 days as recommended by the team based on ground-based studies.

c. Data for FIREX Study

As stated above, several sets of aircraft scatterometer data at L- and C-band exist that have not been analyzed specifically to address FIREX Renewable Resources agricultural research issues. One set is the Colby ASME L- and C-band scatterometer data acquired over irrigated corn, pasture, fallow, and bare (wheat stubble) fields in July and August, 1978. A second set is the L- and C-band scatterometer data acquired over the Cass and Webster County sites in 1980 and 1981 for wheat, barley, sunflower, corn, and soybean fields. Landsat/MSS and NS001 or FSS data are available for the same time frame (only Landsat/MSS for Colby).